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EROSION OF RIVER BANKS.—DISCUSSION ON PAPER No. 600.*

By WILLIAM STARLING, ARTHUR HIDER, SAMUEL H. YONGE, HENRY B. RICHARDSON, HORACE M. MARSHALL, W. P. CRAIGHILL, A. F. WROTNOWSKI and J. A. OCKERSON.

WILLIAM STARLING, M. Am. Soc. C. E. (by letter).—This paper is the first important contribution that has been made to the Society on the subject of the regimen of the Mississippi River by the numerous able military and civil engineers connected with the Mississippi service. Surveys and improvements have been going on ever since 1879, a vast amount of interesting work has been done, and a collection of hydraulic and physical data accumulated, which are of inestimable value, and which, in the magnitude of the scale, in number and in precision, are probably unequaled. They are mostly contained, however, in official reports, in the dry and repulsive form of "Government publications," and are practically inaccessible to most of the profession. Only two or three years ago, the library of the Society did not contain a set of the reports of the Mississippi River Commission. The data, moreover,

* "Erosion of River Banks on the Mississippi and Missouri Rivers," by J. A. Ockerson, M. Am. Soc. C. E., *Transactions*, Vol. XXVIII, page 396.

exist only in the rough, and are of comparatively little service, except to those who have kept up with the progress of the work from the beginning. To classify and digest them properly is a task of both skill and labor. No person is better qualified for such a duty than Mr. Ockerson, who has been connected with the survey ever since its organization, has been in charge of most of the work, both in the field and in the office, and is personally familiar with the phenomena he describes. The information which is conveyed to the reader in the convenient form of "tables" represents an amount of labor which can only be appreciated by those who have themselves undertaken work of a similar kind.

Mr. Ockerson's investigations evidently lead him to the conclusion that the Mississippi has never departed very far from its present bed, so far as is shown by any evidence now accessible. This conclusion is not uncontroverted. Many geologists have maintained that the river has wandered entirely over its alluvial basin, and has built it up, indeed, by such excursions as is, I believe, conceded to have been the case with the Missouri. On this supposition, the whole of the flood-plain, from hill to hill, is of strictly alluvial and modern formation, the work of the river in its present state. The sounder doctrine, however, appears to be that of Professor Hilgard, supported by later investigators,* that the floor or foundation of the flood-plain is of pre-alluvial, though still of quaternary, origin, and that it is merely overlaid by a thin "veneer" of alluvium. There is a trough in the middle of the plain through which the river runs, and from side to side of which it wanders, cutting its way on one bank and building on the other. The greater portion of the plain adjoining this central trough is probably of very late origin—in fact, some of it has been built within the memory of man.

Mr. Ockerson's conclusion, that "the lateral oscillation of the stream is really confined to rather narrow limits," is confirmatory of Prof. Hilgard's view.

The statement that "no great amount of caving occurs at high water" appears to me to require some modification. I believe it to be true that on the whole there is more caving on a falling than on a rising river, but I should hesitate to say that the period of greatest activity

* See, especially, Professor McGee's monograph on the Lafayette Formation, Washington, 1891.

was from a medium stage down. I should rather think it was from a high stage down to medium. Instances of high-water caving are so numerous and of such magnitude that they can hardly be regarded as mere exceptions. As a notable example of a cave at the extreme height of a considerable flood, in May, 1886, at Dennis Landing, in Mississippi, a "pocket" caved away to the depth of 500 ft. in one day. At Greenville, in 1891, the bank caved back 1 100 ft., nearly all of which damage was accomplished during extreme high water, while the river was several feet over its banks. Moreover, in this bend, the principal caving is always at this stage. At Shipland Landing, the upper portion of the bend caves during low water, the lower portion at extreme flood. At Leota, the caving is usually at high water, though it is worse when the river is receding than when it is advancing. At this point, for two or three years, the annual rate of caving was 700 or 800 ft. At Longwood, it was nearly the same. At Hall's Landing, in the spring of 1886, the bank caved back about 1 000 ft. In all these instances, the caving ceased at a medium stage. In fact, where the current is very swift, the angle of presentation of the bank very abrupt and the material light and friable, I do not think it makes much difference whether the river is high or low, rising or falling. Where the current is only moderately strong and the other conditions not very unfavorable, the bank may be gradually undermined for a long time, and yet be sustained by the lateral pressure of the water. When the latter falls, its support is withdrawn and the bank falls with it.

Other things being equal, it would seem that the caving should be greatest when the river is up and the volume of water most considerable; and, within my limited sphere of observation, this appears to be the case.

"Low-water caves," I think, are generally immediately due to the shifting of the channel. Very commonly there is a high-water and a low-water channel, one being next, we will say, the left bank, the other next the right. During flood, then, the river will cave on the Mississippi side, while at low water it invades the Louisiana shore. These low-water caves are sometimes very formidable. Duvall's Landing, in Mississippi, is a case in point. This bank caves only between medium and low water, the high-water channel being on the Louisiana side. At flood tide it is almost dead water next the Mississippi bank. Yet from 1887 to 1893 this bank has caved nearly 3 000 ft.

In all caving, the material which has sloughed away lodges at the foot of the bluff bank, forming a talus like that at the foot of a cliff. Here it remains until it is washed away by the current, the caving, in the meantime, of course, being suspended. As soon as the talus is removed, the caving process recommences. This may be repeated several times in one season or not, according to the nature of the situation, the material and the strength of the current. Sometimes the sloughed mass of earth, roots and trunks lies and serves as a natural revetment for years.

Low-water caving may sometimes be due to the local development of an extraordinarily steep low-water slope. For instance, from Arkansas City to Vicksburg, the high-water slope of the water-surface is not far from uniform, while the low-water slope is very variable. For the year 1888, the difference was as follows:

	High-water slope.	Low-water slope.
Arkansas City to Greenville, 40.2 miles...	0.323	0.169
Greenville to Lake Providence, 63.8 miles.	0.327	0.293
Lake Providence to Vicksburg, 56.9 miles.	0.307	0.509

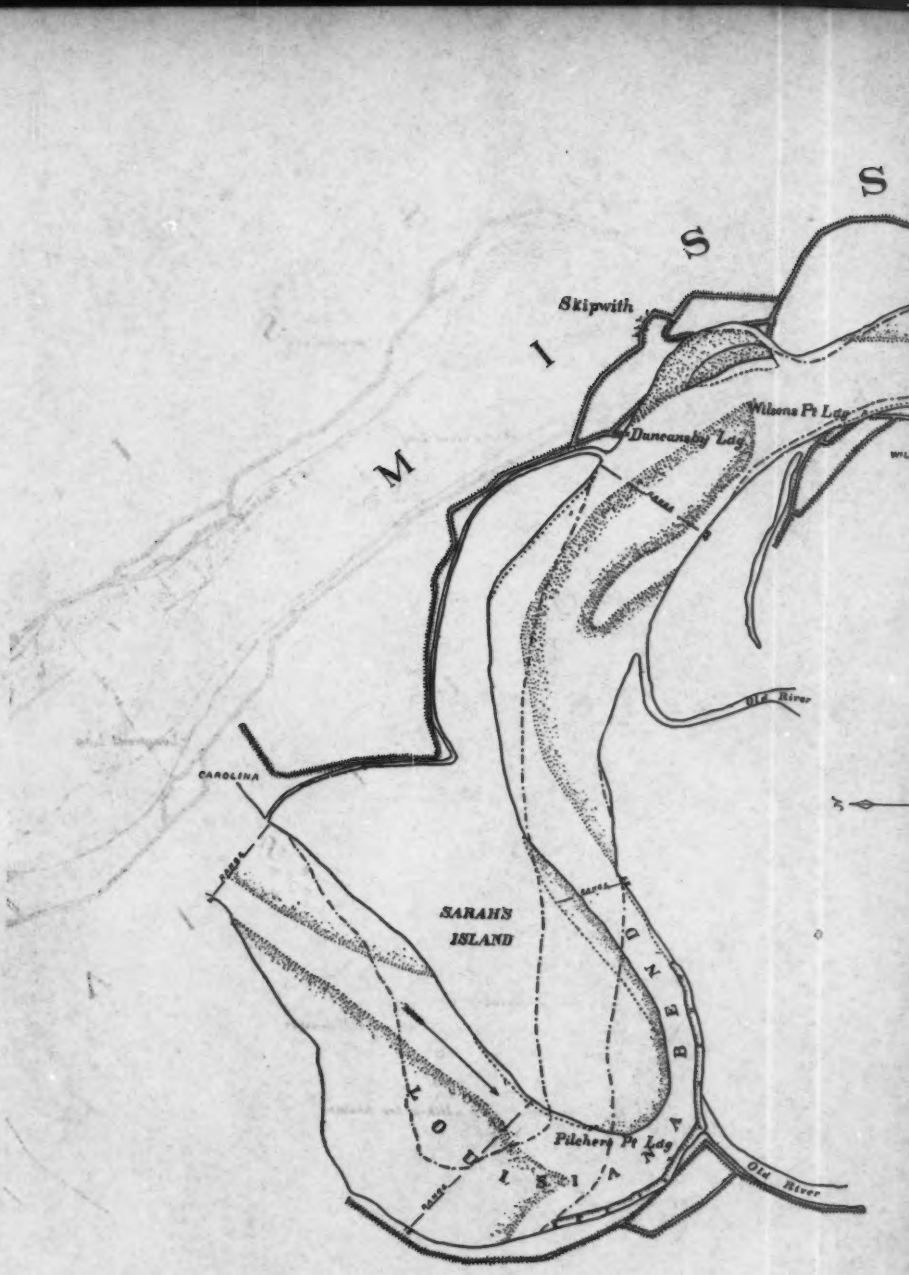
The great development of low-water caving between Lake Providence and Vicksburg may not improbably be due to this cause.

One peculiar form of caving is worthy of notice because it is important in its effects upon works of river improvement. This, so far as I know, was first brought to notice in print by Mr. Ockerson himself in one of his reports to the Mississippi River Commission, in 1884. It consists in a sloughing of the bank due to the immediate neighborhood of ponds or streams. The water from these sources infiltrates the soil of the bank and causes a slipping or sliding of the latter, not usually of great extent, unless other circumstances conspire, yet sufficient to be very destructive to bank-revetment or similar works. This, of course, generally occurs at stages below the medium.

Mr. Ockerson's paper must always be of great value to the student of the Mississippi or similar streams.

ARTHUR HIDER, M. Am. Soc. C. E. (by letter).—The data given in the paper of Mr. Ockerson will be of great value as a basis for future comparison of the changes that are continually in progress in these two great rivers.

The facts presented clearly demonstrate that, while the oscillation of the thalweg of the Mississippi River is very considerable in extent,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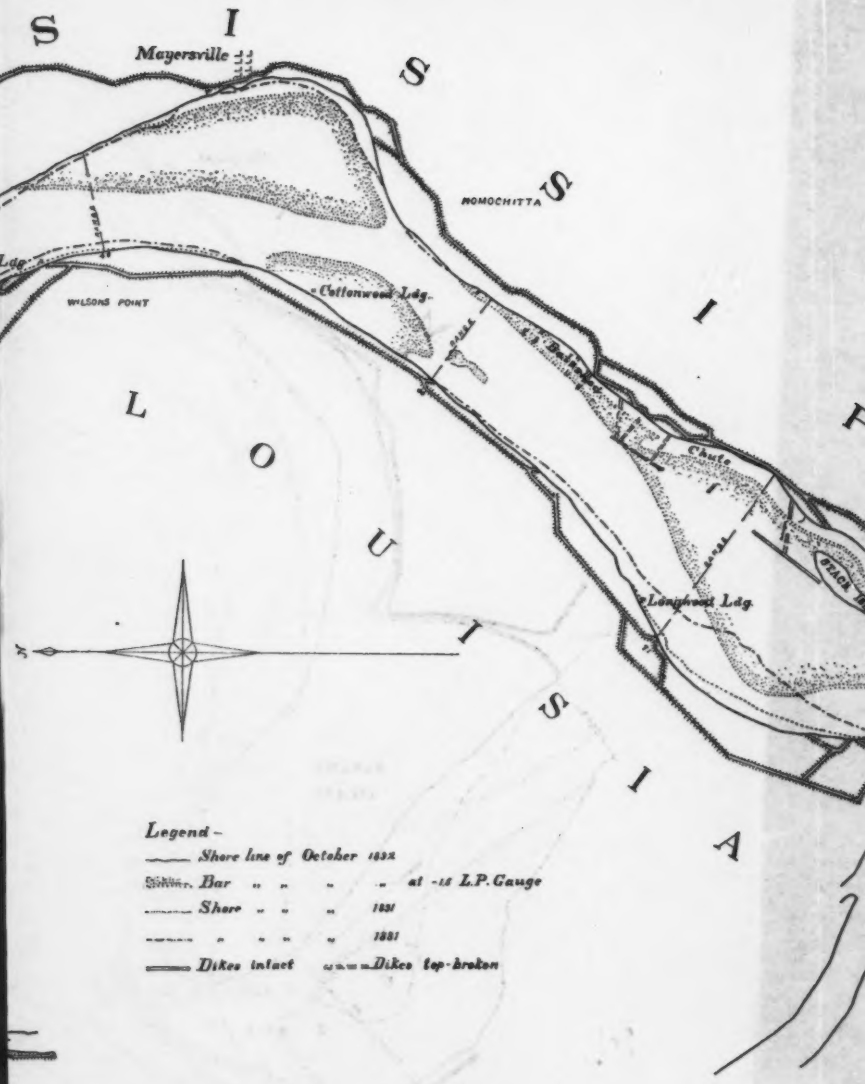
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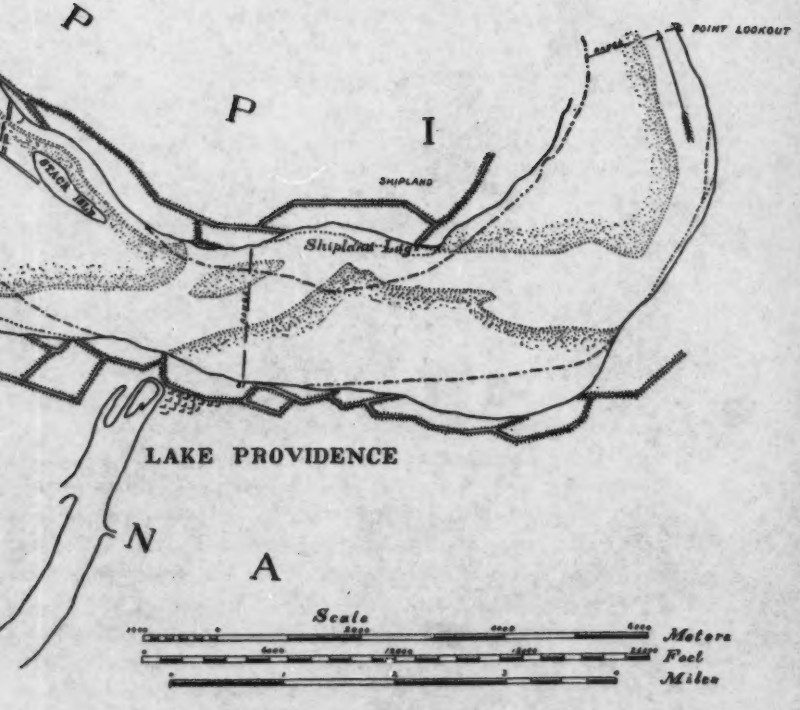
WILSONS POINT
Cottonwood Ldg.
Chute
Longwood Ldg.
Legend –
Shore line of October 1932
Bar " " " " at -15 L.P. Gauge
Shore " " " 1931
" " " " 1881
Dikes intact
Dikes top-broken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still the lateral movement as a whole is much less than has generally been supposed; in fact, the variation in the position of the bed of the river from year to year is confined within comparatively narrow limits. It is to be regretted that the absence of fixed reference points in the earlier surveys prevents a closer comparison. The results given, based on the most accurate data obtainable, have been collated, not without an immense amount of care and labor, and great credit is due to the writer of the original paper for presenting such a mass of valuable information in so clear and comprehensive a manner.

While the preponderance of evidence leads to the conclusion that the river has remained for several generations, and will probably continue, in about the same relative position in the valley, still, the lateral movement is so great from year to year that the problem for the final improvement of the river resolves itself into giving permanency and stability to the banks and confining the active forces of the river to the bed of the stream itself, thus preventing its energy being expended in undermining its own banks. When this is accomplished it is believed that the shoals at the crossings will disappear and the channel at these places, even at the lowest stages, will have both sufficient width and depth to meet all demands of commerce.

While it is true that caving is generally most active on a falling river, at about mid-stage and below, it is nevertheless a fact that in some localities, at times, the caving is most rapid during high-water stages. At Greenville, Miss., the bank recession during the high-water stage of 1890 for two miles or more above the town, due to erosion and caving, was an average of 500 ft., being 1 100 ft. at one point; this caving took place at flood stage in less than three months.

High-water caving is not infrequent on the Mississippi River between White River and Vicksburg, and is often so rapid as to destroy the levees, occurring as it generally does where it is not anticipated. This high-water caving is probably due principally to erosion caused by changes in the direction of the current above, the main energy of the stream being directed to a particular point of attack, while the current is at its maximum velocity.

A map (Plate I) of what is known as "Lake Providence Reach," beginning at Carolina Ldg., 517 miles below Cairo, is submitted as giving additional data. Careful surveys under the direction of the Mississippi River Commission have been made from year to year on this

portion of the river, based on the triangulations referred to in the original paper. A comparison of the surveys indicates a gradual increase of high-water widths due to caving.

These surveys were plotted to a scale of 1 to 10 000, and the widths measured by scale.

Length of river compared, 7 miles.
Mean high-water width, 23 sections compared.

Ranges 39 to 61. Date of survey.	Feet.
1882	5 824
1883	5 802
1884	5 882
1886	5 909
1888	5 962
1890	6 109
1891	6 184
1892	6 452

Length of river compared, 6 miles.
Mean high-water width, 21 sections compared.

Ranges 61 to 81. Date of survey.	Feet.
1882	6 005
1883	6 048
1884	6 057
1886	6 299
1888	6 595
1890	6 833
1891	6 962
1892	7 370

COMPARISON OF SURVEYS L. P. REACH FROM 1883 TO 1892, EXCLUDING CHUTES.

68 ranges compared. Distance, 22¼ miles.	Year.	Mean low-water width.	Mean areas.	Mean maximum depths.	Mean depths.
Range 14 to 81	1883	2 222	44 859	41.5	20.2
" 14 to 81	1884	2 328	50 141	44.9	21.5
" 14 to 81	1885	2 459	50 506	42.5	20.6
" 14 to 81	1886	2 595	50 888	40.3	19.7
" 14 to 81	1887	2 731	51 100	38.1	19.7
77 ranges compared. Distance, 25¼ miles.					
Range 5 to 81	1888	2 900	58 906	40.2	20.3
" 5 to 81	1889	2 787	54 759	38.8	19.6
" 5 to 81	1890	2 673	50 036	37.6	18.8
" 5 to 81	1891	2 197	41 873	34.3	19.1
" 5 to 81	1892	2 255	43 108	38.4	19.1

INCLUDING CHUTES.

68 ranges compared. Distance, 22½ miles.	Year.	Mean low-water widths.	Mean areas.	Mean maximum depths.	Mean depths.	Mean high-water widths.
Range 14 to 81.....	1883	2 423	51 869	43.2	21.4	5 471
" 14 to 81.....	1884	2 588	52 310	45.4	20.2	5 518
" 14 to 81.	1885	2 701	40 627	42.9	15.1	5 642
" 14 to 81.....	1886	2 812	43 008	40.4	15.3	5 771
" 14 to 81.....	1887	2 911	40 653	38.0	13.9	5 906
77 ranges compared. Distance, 25½ miles.						
Range 5 to 81	1888	2 877	49 896	40.1	17.3	6 001
" 5 to 81.....	1889	3 086	56 645	38.8	18.3	6 146
" 5 to 81.....	1890	2 929	52 535	37.4	17.9	6 287
" 5 to 81.....	1891	3 056	44 292	38.0	14.5	6 588
" 5 to 81.....	1892	2 766	45 347	38.3	16.4	6 737

The maximum bank recession due to the caving at any one locality in the 10 years was in the vicinity of Pilcher's Point, and was 4 500 ft. It will be noticed at Sarah's Island that the river has moved to the west more than the width of itself in the 10 years covered by these surveys. By reference to the maps submitted, it will be observed that at nearly all localities where caving has been most active in a bend there is a large sand bar on the opposite side of the river.

Caving of the banks in concave bends generally takes place from the following causes:

The yearly accretions made to the bar on the opposite side during each successive high water, together with the deposits made during the high water in the bend itself, have the effect of decreasing the area and capacity of the previous low-water channel. As the water begins to fall and mid-stage is reached, the channel capacity at the particular point is not sufficient to pass the flow.

To re-establish a water-way of the proper size, scour takes place along the concave bank as offering the least resistance to erosion, a widening of the channel and a consequent undermining and caving of the banks follows, as the water continues to recede to a lower stage, until equilibrium is restored, when the caving for the time ceases.

The continued recession of the bank lines in bends, due to caving, and the consequent changes in the channel below, preclude the adoption of any system of permanent improvement not having for its main feature stability and permanence of the bank itself; any other plan will fail to give satisfactory results.

It may be of interest to state briefly what has been done recently in this direction in revetting parts of four of the worst caving bends between the mouth of White River and Vicksburg, and the measure of success achieved. This work has been done under the supervision of the Mississippi River Commission, an officer of the Corps of Engineers having direct charge of the improvements. This portion of the river is selected on account of the writer's familiarity with the work, having been in local charge of the improvements when they were made.

Before giving a description of the work, it may be well to state briefly the plan of construction adopted, which was essentially the same for all the different works. The method of procedure was as follows:

First.—To grade to the water's edge, at low stage, the nearly vertical banks, which are from 30 to 40 ft. above low water, to a slope of 1 to 4 by the use of a hydraulic grader specially designed for this purpose, filling up the holes and washouts with scrapers and by hand until the slope was fairly uniform.

Second.—To construct mattresses of willow brush and poles from 2 to 4 ins. in diameter, and from 30 to 50 ft. long. These mattresses were built on boats constructed for the purpose. The mats, while being built and sunk in place, were held out in the river from mooring barges, placed at right angles to the bank, the mooring barges and upper end of the mat being held in position by wire cables securely fastened to proper anchorages on shore.

Third.—After the mat was constructed, usually from 500 to 1 200 ft. in length, and from 250 to 300 ft. in width, it was sunk in place by first distributing over the entire surface sufficient stone to destroy its buoyancy; then barges of stone were floated across the head of the mat, just below the mooring barges, and enough stone thrown on the mat to sink the upper 100 ft. to the bottom; the barges were then allowed to drift slowly down stream, stone being thrown on the mat until it was in place on the bottom. The usual quantity of stone used on these mats was ½ cu. yd. of loose stone to each 100 sq. ft. of surface.

Fourth.—After the mat was in position on the bottom of the river, the upper-bank slope from the low-water to the two-thirds stage was paved with rip-rap, laid closely by hand, to an average depth of about 10 ins.

The average quantity of material used for each 100 sq. ft. of mat-

tress was .87 cords of brush and poles, and 0.5 cu. yd. rip-rap. For paving on the upper slope, 4.5 cu. yds. of rip-rap per linear foot of bank.

The average cost per linear foot was $28, to which should be added, for repairs to plank and deterioration of same, and surveys, etc., 25%, making the cost per linear foot of completed work about $35.

Lake Bolivar Front Revetment, 417 miles below Cairo.—The object of this revetment was to prevent the further caving of the bank in front of the Lake Bolivar Levee, one of the largest levees in the State of Mississippi, built several years ago, and crossing the head of Lake Bolivar. The main current of the river set against this bank, and the caving had been rapid for several years previous, which, if allowed to continue, would in a short time have destroyed this large and important work, requiring a new location of the levee system behind the lake and leaving a number of valuable plantations without levee protection.

This revetment was built in the fall of 1888. The entire length of the bank revetted was 4 250 ft.; on the upper 3 300 ft., the mats were 250 ft. wide; the last mat, 1 100 ft. long, was only 180 ft. wide. The brush revetment was made continuous to the top of the bank, and afterwards covered with stone sufficient to keep it in place, to which has been added on the upper bank-slope, in the way of repairs, additional stone to make the slope about 10 ins. in thickness.

The reduction in width of the lower mat from 250 to 180 ft. was necessary on account of the high stage of water, rising river, and consequent rapid current and drift accumulations at the time it was constructed. The expectation was to reinforce this narrow mat by sinking one of the full width on top of it the next season. No further work, however, has been done.*

The high stage of water at which this last mat was sunk prevented it extending as far out in the river as it would have done had the work been built during the usual low-water season. The outer edge of the other mats extended from 120 to 130 ft. farther out.

From a careful survey recently made, the mats, where of the full width of 250 ft., were found intact; the narrow mat was found displaced and broken. The set of the current is still against this bank, but no

*For a more detailed description, reference is made to report of Mississippi River Commission contained in report of Chief of Engineers, U. S. A., 1890-92.

damage has been done to the upper end of the work, where the mats are of full width, nor is there any scour shown either through the body of the mats or beyond their outer edge. The work can be considered quite satisfactory.

Ashbrook Neck Revetment, 446 miles below Cairo.—This work was designed to prevent a threatened cut-off between Georgetown and Miller's Bend; the distance across the narrow part of the neck is only 1 800 ft., while the distance following the river is about eight miles. This revetment was begun in the fall of 1890, the caving at the time being quite rapid, and was continued in 1891 and 1892 until 9 400 ft. of bank was revetted; mats, from 250 to 350 ft. wide. At the close of the season's work in 1890, a narrow mat 180 ft. wide and 500 ft. long was built for similar reasons for building the one at Bolivar; this mat did not extend out far enough to protect the under-water slope from cutting during the high water immediately following, and the ensuing season a mat of the full width of 300 ft. was laid over this.

Careful soundings taken over this work in November, 1892, show the work done in 1890 and 1891 in good condition; there are no signs of undermining at the outer edge of the mats, nor has there been any slipping or breaking down of the upper bank-slope. This revetment may be considered a success, as the caving of the upper side of the neck, where the revetment was built, has entirely ceased.

Greenville Harbor Revetment, 477 miles below Cairo.—During the high water of 1890, the river began caving at an alarming rate; at one point the recession of the bank was 1 100 ft. during three months, caving into the river three separate lines of protection levees, and jeopardizing the existence of the upper part of the town of Greenville. The bank here is almost entirely of sand, except for a short distance below the natural surface, and erodes rapidly.

The design of the revetment was to prevent a further deepening of the bend by stopping the caving, and thus offer protection to the levee system and the town itself. Six thousand six hundred feet of revetment was built in the fall of 1891; this was extended up stream, in the fall of 1892, 4 450 ft., making 11 050 ft. of bank protected by revetment; mats, 300 ft. wide.

A careful comparison of surveys made immediately after the construction of the work, and that of April, 1893, shows that the entire work is in good condition, although a general scour or deepening of

the channel is shown along the outer edge of the mats. From 1891 to 1893, two high waters intervening, the average scour was 11 ft.; from 1892 to 1893, one high water intervening, 3 ft. In other words, the average scour the first year was 8 ft., and the second year, 3 ft., or less than one-half.

Louisiana Bend Revetment, 523 miles below Cairo.—The purpose of this improvement was to prevent further deepening of the bend, which had moved westward, in the last 10 years, 4 500 ft. more than the entire width of the river itself. The continued caving caused changes in the channel of the river below, which it was desirable to prevent.

In 1889, 6 034 ft. of revetment was constructed; in 1891, the revetment was continued down 5 224 ft., and in the fall of 1892, 5 835 ft. additional was built, making the entire length of the revetment in this bend 17 583 ft. The work done in 1889 is all in place, being now protected from the direct action of the current, except at high-water stage, by a sand bar formed since the work was built; the work of 1891, so far as can be determined from comparison of later with former surveys, is in good condition. Surveys made over the revetment of 1892, both before and after the mats were in position, and during the three months following, without, however, an intervening high water, indicate that on many of the sections a scour was taking place, not only along the outside of the mat, but through the body of the mat itself.

The Bolivar and Ashbrook Neck revetments show no scour, either through the mats themselves or at the outer edges. At Greenville and Louisiana Bend, scour, both through the mats and immediately beyond their outer edge, has taken place. Why this should be the case in the two latter instances, and not in the former, can only be accounted for by the existence of different conditions, as the mats at both Greenville and Lousiana Bend were of full width of 300 ft. As these four revetments were constructed in the most rapidly caving bends, where the lateral movement of the river was greatest, it would be expected that the resistance offered by the revetment in preventing erosion next to the bank would naturally result in a scour or deepening of the channel beyond the outer edge of the mats.

It would seem that the maximum rate of scour occurs after each high-water stage, and if the revetment has sufficient strength to withstand the attack until the necessary enlargement of section takes

place, there will be a gradual shifting of the line of deep water toward the bar on the opposite side and an eroding of the bar accretions deposited at preceding high waters.

As the natural result due to holding the bank in a caving bend is a steepening of the slope between the bank line and deep water, the importance of having a revetment so constructed as to permit a limited scour through it while these changes are in progress, and at the same time to have pliability enough to adjust itself to the changed conditions, is evident; at the same time the revetment should be constructed of such material as is lasting, so that no renewals will be required.

The work cited above shows what has already been done in the direction of holding some of the worst caving banks on the Mississippi River. It is too early to state positively as to the permanency of the works; so far they promise satisfactory results.

Improvements in methods will continually be made, as experience is gained as to the proper treatment of this river, and future engineers, profiting by our mistakes, will eventually solve the problem, how to prevent the "Erosion of the River Banks on the Mississippi and Missouri Rivers."

Samuel H. Yonge, M. Am. Soc. C. E. (by letter).—It has been my practice for many years, while in charge of the construction of works of improvement on the Missouri River, to compute the volume of erosion in caving bends in the vicinity of my work. I have found the average height of the prism of erosion to be about 35 ft. for bends, and about 27 ft. for towheads and first benches. As the greater part of the erosion occurs in the bends, possibly as much as 75%, the figures given by Mr. Ockerson for erosion of Missouri River banks are probably close approximations. The character of the 140 miles of the Missouri River between Sioux City, Ia., and the mouth of the Niobrara River being the same as that of the river below Sioux City, it appears proper, in estimating the volume of erosion, to apply the annual rate determined by Mr. Ockerson to 942 miles of river. This would make the total quantity of material washed into the river from caving banks about 702 670 000 cu. yds.

Above the mouth of the Niobrara the Missouri Valley is narrower, and the bank erosion, for this and other reasons, is less than below that point. This deficiency, however, is probably made up for in a great measure by the eroded material and surface washings brought in by the

upper tributaries. The extent of these contributions, as well as of those coming from tributaries below Sioux City, is not known. It is, therefore, obvious that the total quantity of material washed into the Missouri is far greater than estimated, and this view is sustained by the following:

It is found, by sounding the same cross-section of the river at all stages, that the section is deepened by scour during floods, and filled back during the lower stages, when bank erosion is greatest.

The extent of the scour and "fill-back" varies in different localities and for different conditions of flow.

From data collected at several points between Sioux City and the mouth of the Missouri, it appears that the change in area of cross-section on account of "fill-back" is from 3 000 to 8 000 sq. ft.; 5 000 sq. ft. appears to be about an average. This would amount to about 978 000 cu. yds. per mile, or over 30% greater than the estimated bank erosion. The excess of "fill-back" over bank erosion is probably supplied by tributaries. The "fill-back" is set in motion whenever the stage is higher and the current swifter than that at which it was deposited. The distance it is carried each year, and its rate of travel at any given stage, cannot be directly determined.

As the average annual volume of bank erosion is apparently constant, and as new river banks do not build up any more rapidly than the old ones are eroded, and, furthermore, as the general elevation of the thalweg is practically the same from year to year, it is to be inferred that the volume of eroded material that is swept into the Mississippi each year from the Missouri and its tributaries is not less than that of the "fill-back."

A series of sediment observations made on the Missouri at St. Charles, Mo., about 20 miles above the mouth of the river, in 1879, shows the total volume of sediment carried in suspension to be about 188 900 000 cu. yds., or about 20.5% of the whole volume of "fill-back," and about 27% of the total bank erosion between the Niobrara and the mouth of the Missouri.

During a part of the period that the above sediment observations were being made at St. Charles, viz., from the middle of February till the latter part of June, similar observations were made for the Mississippi at Columbus, Ky.

By allowing a time interval of three days between St. Charles and

Columbus, it was found that about the same volume of sediment observed passing St. Charles also passed Columbus.

If the total volume of eroded material that is brought into the Mississippi is to be considered, and a comparison instituted between it and the quantity of sediment passing New Orleans, the material contributed by the Missouri and the reach of the Mississippi between the mouth of the Missouri and Cairo should also be taken into account. Assuming for the latter the same annual rate as for the Missouri would make the total volume of eroded material that annually goes to build up the delta of the Mississippi equal to about 1 727 500 000 cu. yds. This quantity is still further increased by material from the Upper Mississippi, the Missouri above the Niobrara, the Ohio and the lower tributaries, for which data do not exist or are not at present available. Accepting this view, the sediment observed passing New Orleans probably represents not more than about 16% of the whole volume of erosion.

The failure of sediment observations to account for anything like the whole volume of eroded material may be explained by the fact that only the finer particles of silt are carried in suspension by the water, and thus come within the range of actual observation, the coarser materials being rolled or moved along the bottom.

Humphreys and Abbott estimate the total volume of material "pushed" into the Gulf annually at 750 000 000 cu. yds. They also state that the river water is distinguishable in the Gulf 20 to 25 miles beyond the bar during flood stages, and from 5 to 10 miles at low stages.

In conclusion it is to be understood that the figures I have given are only estimates based on available data. A complete and satisfactory discussion of the subject would require precise data covering the whole river and its tributaries, especially of those tributaries flowing through the "Bad Lands," from which a very large proportion of the silt is derived.

HENRY B. RICHARDSON, M. Am. Soc. C. E. (by letter).—Mr. Ockerson's paper presents a large body of facts in an interesting field for investigation which appears heretofore not to have been very thoroughly explored, and it suggests inquiries which may hereafter lead to important conclusions as to the proper methods of improving the Mississippi, Missouri and other alluvial rivers.

The establishment by the Mississippi River Commission of the "stone lines" described in the paper affords a base for the continuance of investigations as to the amount and rate of bank erosion in the future, and it would seem that a great deal of fairly accurate data as to bank erosion in the past might be obtained by comparison of the land surveys, which were generally made as much as 50 years ago, with the more recent surveys. It would materially add to the interest and value of the Mississippi River Commission's maps if the section lines of the land surveys were shown on them. The river banks, as they existed at the dates of the land surveys—especially on the abrupt, concave sides of the river—could certainly then be retraced with close approximation to truth upon the later maps. The inaccuracies of the original surveys should not greatly affect the result, as a reconstruction of the parts of subdivisions lost by erosion would start from the accurately determined positions of the "back corners" that remain.

It has been demonstrated that all streams in north latitude should tend to crowd upon and abrade their right banks more than their left, and it is frequently asserted that they do so. The explanations of rapid erosion sometimes given when it happens to be on the right bank of the river, as being due to this cause, must always have appeared more fanciful than real to anyone who looked much beyond the immediate locality of such erosion; but Mr. Ockerson's tables show us that whatever theoretical value may be allowed to this tendency of rivers—and railroad trains as well—to "turn to the right as the law directs," it has only negative results on the Mississippi and Missouri rivers when taken together, as the aggregate area of erosion on their right banks is shown to be less than 87% of that on their left banks.

While it is undoubtedly true that the amount, and especially the rate, of lateral movement of the banks of these rivers is popularly much exaggerated, it is evident that, if continued indefinitely, at even the moderate average rate, as deduced from Mr. Ockerson's tables, of only about 90 ft. per annum, the bends would finally develop to the right and left until they might occupy the entire width of the alluvial valleys, were it not that long before such limits could be reached they must inevitably inosculate and form "cut-offs." There are indications far inland from the present banks of the Mississippi that its channel, or the channel of some large arm or branch from it, had its bed at one time or another in almost every part of the alluvial valley. Many

of the curved lakes and sloughs that abound in the interior present all the characteristics of the old river cut-off lakes, whose origin is undoubted, and only differ from the more recently formed lakes in being more generally silted and overgrown with cypress trees, and in remoteness from the present course of the river.

A somewhat curious case of repeated cut-offs in the same place appears to have occurred at Lake Concordia, just above Natchez. It would appear from an inspection of the map that two successive cut-offs have already taken place here, and that a third is now threatened; and that the location of both of those that have already occurred must have been in almost exactly the same latitude as that now threatened, and not more than a mile or two distant.

If cut-offs could be entirely prevented, it seems a logical conclusion that the river must in time attain such a length and consequent diminution of slope that all erosion due to the direct force of the current would finally cease. But the operation of the natural forces that produce bank erosion has undoubtedly been producing such cut-offs from time to time during long-past ages, though there are not wanting instances, besides those near the mouth of Red River mentioned in the paper under discussion, in which the hand of man has assisted Nature, or at least hastened the accomplishment of her work. Among these may be noted the Palmyra cut-off of 1867, where a ditch had existed for years previous, which had been gradually enlarged, so that the year before small steamboats had passed up through it in time of high water. So, also, the cut-off of 1884, at Cole's Point—although the paper seems to intimate that the place where the river broke through was not on the line of the ditch which had been cut there years before—was certainly of a width, when first observed as a cut-off, that extended about equally on either side of the line where the ditch had been. This ditch, by the way, had been slowly enlarging for a number of years, though a cut-off was not immediately apprehended previous to the time it took place. In 1878 a measurement of this ditch showed it to be 60 ft. wide and 15 ft. deep about 100 yds. from its lower end, though considerably narrower near its upper end. The well-known canal cut by General Grant in 1863 across the point opposite Vicksburg still remains well inland from the bank of the river, as cut off in due course of natural causes in 1876, and probably was never really expected to accomplish the purpose for which it was ostensibly made.

Mr. Ockerson shows that the maximum rate of erosion on the Mississippi lies in the stretch of about 150 miles between Grand Lake, Ark., and Waterproof, La., and states that "the area of greatest caving coincides with the leveed portion of the river." But, as only about 65 miles of this stretch of maximum erosion has levees on both sides, while the remaining 85 miles does not appear to differ in its proximity to the hills from the stretch of about 175 miles next below, where the rate of caving becomes much less, it hardly seems a coincidence that should carry any such weight of suggestion regarding an "intimate relation" between the levees and the caving banks as would have arisen had the leveed part of the river and the area of greatest caving been coterminous as well as coincident. Greater velocity of current and greater range of stage should be found in a leveed stretch of river than in an otherwise similar unleveed stretch, and, therefore, greater erosion of bed and banks might be expected; but there seems to be no direct proof of it in the coincidence referred to.

The author of the paper also notes that timber growing on the banks has no appreciable effect in arresting caving, and that excessive caving and excessive curvature are rarely coincident. What, then, are the causes of the excessive bank erosion along this 150 miles of river?

It is shown that on the Missouri River the annual area of erosion per mile of river is greater than on the Mississippi by over 40%, and that "in general the banks of the Missouri are composed of fine sand and silt," which may indicate that this character of material in the banks is a cause for their greater erosion—a conclusion which might suggest itself as not unreasonable on other grounds. If we take Table No. 1, and assemble the several items according to their classification under the column headed "Character of Banks," putting in one class all such items as are classed "sand," "sandy," "mostly sand," "sand and silt," etc., we find that the average rate of caving for such banks amounts to about 30.3 sq. yds. per linear yard of caving bank, while the average for all classes of caving bank is only 24.2 sq. yds. We also find that the length of caving bank of this sandy character is greater per mile of river in the 150 miles subject to excessive erosion than in other parts of the river, being at the rate of 718 yds. per mile; while in the stretch of 510 miles above it is about 503 yds. per mile, and in the 225 miles below only 462 yds. per mile of

river. The result of this comparison, as far as it goes, tends to the conclusion that one of the causes of excessive erosion in the 150 miles of river between Grand Lake and Waterproof may be the excess of sandy banks in this stretch. But, while the average annual rate of caving of sandy banks, as above stated, is 30.3 sq. yds. per yard of caving bank in the whole 885 miles covered by the table, the average annual rate in the 150 miles subject to excessive caving is 55.4 sq. yds. per yard of caving bank, which would indicate that the excess of sandy bank is not the only cause of excessive erosion in this stretch.

Mr. Ockerson notes as a probable cause of excessive erosion the increase of slope due to the Cole's Point cut-off in 1884. But if we go back about 19 years and consider the relative length of river channel then, and its length in 1891, in the stretch of 150 miles of excessive caving, there appears still greater probability that increase of slope may play an important part among the causes of excessive caving in this stretch. Besides the Cole's Point cut-off—the lower end of which is only about seven miles below the limit of the 150-mile stretch considered—there have occurred within the limits of the same stretch, since 1865, the Terrapin Neck cut-off in 1866, the Palmyra cut-off in 1867, and the cut-off opposite Vicksburg in 1876, besides a number of cases where the main channel of the river has forsaken the longer course it followed in 1865 and taken shorter chutes, as at Islands 95, 97, 103, Diamond Island Towhead and Grand Gulf Island.

It is not difficult for any one familiar with the river during the past 30 years to trace a line on the maps published by the Mississippi River Commission that will represent with approximate accuracy the center of the main channel as it was in 1865. The distance along such a line—giving it the greatest length possible where there is a reasonable doubt as to its exact position—from Grand Lake to the lower end of the Cole's Point cut-off is 205 miles. The length of channel line between the same points in 1884 was 157 miles, showing a decrease in length of over 23%, with a proportionate increase of slope.

The development of channel line in the stretch of river from Cairo to Grand Lake is about 1.76 times the length of the shortest line between the two points, and in the stretch from the lower end of Cole's Point cut-off to Donaldsonville, it is nearly the same, or, say, 1.82 times the length of the most direct line down the alluvial valley. But in the intermediate stretch of excessive erosion between Grand Lake

and the lower end of Cole's Point cut-off, the length of the river is now only about 1.67 times the length of the most direct line down the valley between the termini, while in 1865 it was at least 2.18 times its length.

One of the probable causes of caving mentioned in the paper under discussion is the return flow (when the rivers fall) of the water that has penetrated and saturated the banks while the river was at a high stage. This effect would evidently be somewhat proportionate, other things being equal, to the range between high and low water, and therefore, in a general way, should be smaller below the mouth of Red River than above, as the oscillation becomes less from that point down to the Gulf than it is above. But in the 150-mile stretch of excessive erosion, the oscillation between high and low water stages is not materially different from that of the other stretches included in Mr. Ockerson's table, and if the greater oscillation of the upper part of the river has any influence in producing greater erosion in this 150-mile stretch than in others immediately above and below it, it can only be in consequence of the more sandy and porous character of the material composing the banks.

If we ascribe the excessive erosion in this part of the river solely to the character of the material composing its banks, there seems no reason to assume that the locality of excessive erosion will move either up stream or down. If, however, we consider it a result of recent shortening of the channel, and consequent increase of slope, we might conclude that at some future time, when a normal length of line, and a slope adjusted to the character of the bank material has been recovered, the region of maximum erosion may move elsewhere; but that it would more likely move up stream than down, because the apparent opportunities for cut-offs are generally greater and more numerous above than below.

As stated in the paper, "It is plainly evident that bank erosion is one of the principal factors in the solution of the problem of river improvement and control." If the banks in the concave bends of the river can be revetted and held in any fixed position, the opposite banks will tend to adjust themselves to concentric lines, leaving a channel of the requisite width to carry whatever volume of water the river may have between banks. The energy of the current need not, then, be continually expended in removing and rearranging the material brought down by the caving banks, but may attack and disperse

the shoals and bars which now obstruct navigation. This material, once pushed aside and deposited without the channel, would largely remain where it was placed, and not be—as it is in a state of Nature—forever wrought over and over.

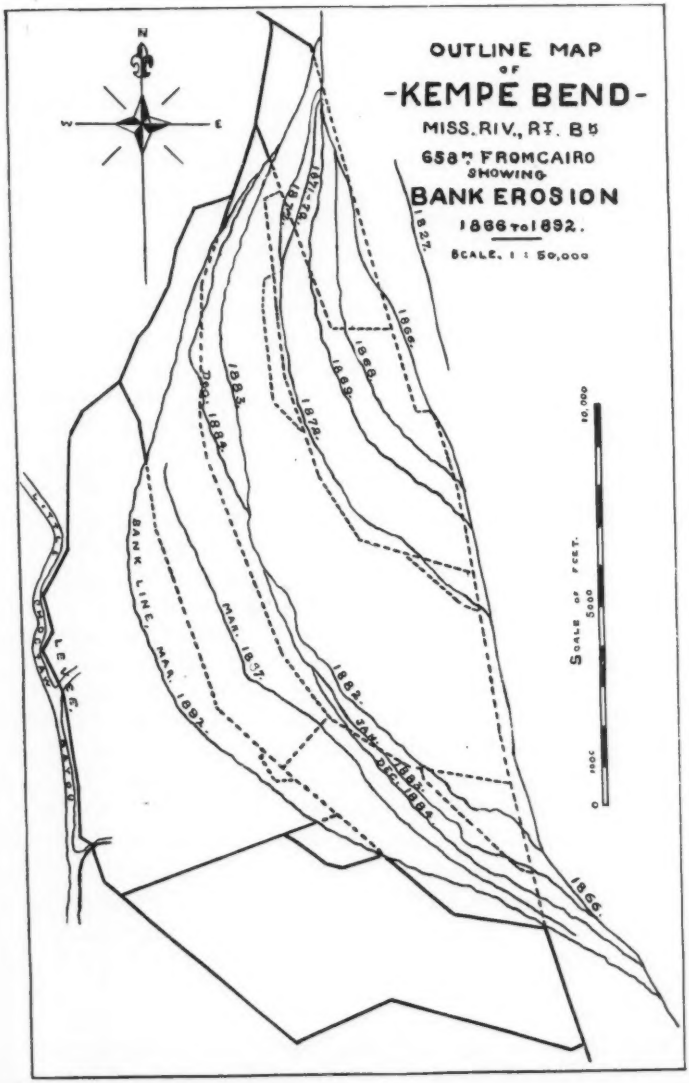
If the banks were fixed in position, there would no longer remain a doubt as to the ease and certainty with which floods could be restrained from overflowing the adjacent lands, as embankments of any size and strength desired could then be built and continuously improved, instead of being, as now, subject to the perpetual encroachment of the caving bank, and the consequent necessity for frequent renewal upon new lines.

As an example of the enormous expenditure of means and labor that is sometimes involved in levee construction consequent upon bank erosion, the outline map of "Kempe Bend," on the Mississippi River, is here presented (Plate II). As will be seen, this stretch of about six miles of the right bank of the river was not a bend at all in 1866, but rather a reach slightly convex to the river. The position of the bank at various dates since 1866, taken from records in the office of the Louisiana State Engineers, is shown on the map, and that of the numerous lines of levee built since that date. The area caved into the river from 1866 to 1892 is about 2 900 acres, involving a great part of three large and productive cotton plantations. The construction of levees made necessary from time to time by the recession of the bank has thus far involved over 2 500 000 cu. yds. of earthwork, at a cost of nearly $1 050 000.

The most difficult and expensive bank revetments on the Mississippi River, have, perhaps, cost as much as $150 000 per mile. But if the two miles, or less, of bank in this bend, which in 1866 comprised the limits of erosion, could have been revetted and held from that time to this, at this cost per mile, there would have been a clear saving of nearly $700 000 in levee construction alone, not to speak of the value of the plantation property lost since then. And even the entire length of about six miles now undergoing active erosion might be revetted at the same rate with a probable margin of profit hereafter.

Horace M. Marshall, M. Am. Soc. C. E. (by letter).—While testifying the highest appreciation of the value of the information contributed concerning "Erosion of River Banks on the Mississippi and Missouri Rivers," yet with greater emphasis must it be said that, to be

PLATE II.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXXI, No. 687.
RICHARDSON ON EROSION OF RIVER BANKS.



presented with so many figures and facts at the finger ends of a prominent engineer who has for a number of years made a special study of river regimen is rather disheartening when not a single dogma is enunciated. The "locality of excessive erosion" seems affected as was the sleepy-headed Irish nurse's patient, "wan toime he is the wan way and thin he is anither way, and thin he is the wan way."

Column 3 in Table No. 1 possibly would have appeared more germane to the subject and more closely related to the column of character if the numbers had placed under them for denominators the distances from the top of the bank out to where the depths obtained, for it is usual to estimate the stability of earth according to its angle of repose rather than its height.

The table would be added to in more than one way by a new column of water-surface slopes, or, better still, by adding also maximum velocity in each reach. Whatever the cause of caving banks, it is quite certain the caving would stop if the caved-in material was not swept away by the onflowing water. It is not meant that maximum slope will be found concurrent everywhere with maximum bank erosion, even though the bank material be the same, for, since change of direction involves loss of force, a greater curvature may counteract the greater slope, or a less mean hydraulic radius have the same effect. Since the variation in bank material of an alluvial river is more local than regional, and the last column of Table No. 1 is cited to bear out the assertion, it follows that the reason of caving which occurs in particular districts must be looked for aside from bank constituents. While the power of the water to do work depends on its velocity which, other conditions being equal, varies with the slope, yet, if the slope be excessive, the scour will not be as great nor the channel as deep as obtains in places of less slope; because the velocity, being due chiefly to slope, is more nearly uniform at all depths, both close to shore and in the channel; hence the scour at the foot of the bank causes caving and change of form of cross-section, which lessens the velocity, or if the current strikes the bank at an angle, the river is moved laterally before sufficient time has elapsed for deepening the bed. In the other case, the velocity, being due principally to depth, is less near the bank, and before the caving begins the channel is scoured and the slope flattened.

Inasmuch as an alluvial river makes its own bed, the slope and

not bank constituents determines its cross-section. So long as its discharge remains constant, the banks must remain stable, but any increase in the flow must bring about caving which will lengthen the river or change the cross-section. Thus it is readily seen how levees cause caving banks. That the caving is not excessive at time of high flood is largely due to the current line withdrawing from the bank towards midstream, as the jetty action of the bars on the convex bank becomes proportionately less with the increase in volume of the river. Scour is going on mean time in the bed, and with the fall of the water this increased depth is carried, by the again bending current, in close to shore, and the banks are undermined. It is not intended to depreciate the effect of the seepage from the banks, but it is hardly to be credited that seepage occurs only in rare instances from opposite banks at the same time. The drainage from the land is everywhere as the water falls, but caving only occurs where the current is close along shore, and usually where there is vortex motion due to the water impinging on the bank. On the other hand, caving does occur when there is no drainage from the land, for beside the many cases of caving at high stages which escape notice by reason of bank submergence, but which are attested by the floating foam on the water, instances are not few where levees have caved into the river at extreme flood, and probably every cut-off takes place near that time; certainly when the water is over its banks.

Turn now to Plate XLII, *Transactions*, Vol. XX, page 228, and imagine a third line nearly equi-distant below and drawn nearly parallel to the low water-line there shown, but somewhat divergent toward the lower right-hand corner; then consider where the depth at high water (indicated by this line) multiplied by the slope would give the greatest product, velocity.

So much for the whence of bank erosion, and now for the whither. Inasmuch as there were 916 miles of caving banks on the Mississippi in 885 miles of river, and 818 miles of caving banks on the Missouri in 802 miles of river, it is certain that the former widened along 41 miles of its length, and the latter along 16 miles of its length. If "it may be accepted as practically true that erosion on one bank is followed by an equivalent accretion on the other," or, "in some cases the resultant of the two is a very large decrease in width," yet the burden of evidence seems to show that widening of the river contributed some

"of the solid matter passing New Orleans, computed to be about 10 square miles, 26.8 ft. deep." If this is the measure of the widening, and all the rest of the material from caving banks is taken up by accretion on the opposite shore, some other source of supply must be drawn on for the sediment passing New Orleans. The widening on the Mississippi along 41 miles of average bank would cover 10 square miles 3.7 ft. deep, and the Missouri contribute but 1.1 ft. more; and since the Upper Mississippi, Ohio, Arkansas and Red rivers cannot individually do more, it follows that the river-bed must contribute an amount equivalent to 0.2 ft. deep half a mile wide over the whole of its length of 885 miles.

A glance at Plate L, *Transactions*, Vol. XXVIII, page 398, reveals a notable decrease in the number of islands, notwithstanding the similarity in the location of some. By count the early sketch shows 30 below Les Côtes de Yazous, the later map but 9 below Vicksburg, excluding cut-off islands which do not occupy a part of the river's bed. The numbers in the next stretch to the Arkansas River are 57 and 20 respectively, to Memphis, 49 and 21, and to the mouth of the Ohio, 70 and 23. A considerable number of islands, then, have been carried down to the sea or become merged in the banks by this mighty river, and little more than a century serves to record a clearing of its channel and a concentration of its waters.

The answer to the next and possibly most important question of the whither of the bank erosion involves another: What of the bottom?

The generally accepted belief is that clearing, cultivation and ditching have accelerated the drainage of the water into the rivers; this, with the confining by levees, would produce a greater flow at time of flood which would give rise to increased velocity, which in turn would cave the banks or scour the bed, till the increased frictional resistance or the flattened slope restored the equilibrium. Since the larger river in alluvial soil has the flatter slope, it must be that it is the channel that is deepened by the concentration. The flood height has not been raised to any considerable extent, except locally, so the increase in volume did not take place on top; and yet so short a period as twenty years has prefixed a minus sign to nearly every low-water reading on gauges which were set with zero at "lowest water ever known." It would seem then, that all the solid material brought by

its tributaries, as well as some from its islands, bottom and banks, is cast from its bed or carried out of its mouth.

Cross-sections of Red River, repeated after an interval of 21 years, show, when plotted above the same datum, that the river has widened somewhat and deepened considerably. Level elevations show that the surface at "high water" has risen locally, the line has leveled up, and at "low water" has fallen gradually. The discharge at the same gauge height, during low and medium stages, has nearly doubled. There are no early measurements at time of high water.

To sum up, then: Quickened drainage increases the volume which in turn increases the velocity, and causes caving and scour, which flatten the slope or increase the friction, till the working power of the river and the resistance of its bed are again balanced. The completed river has a larger cross-section, discharges more water with a diminished mean velocity; but because of the increased reservoir capacity of the river-bed, its oscillation may not be altered, its maximum discharge may not be increased, and its period of low water may not be prolonged, even with its greater depth.

Much of this is what is commonly termed theory, but, like most that masks under that title, is only surmise; it suggests, however, a thought of that part of the paper under discussion, where in classic period the author felicitates the future engineer who shall announce the law of water's ebb and flow adduced by present labors. Mayhap, when the time comes round, the future engineer will not adjudge those of this day and generation more prescient than a Humphrey or an Abbot, for while they marked their measure by perishable monuments, we of to-day may be omitting altogether measurements equally important in formulating conclusions.

W. P. Craighill, M. Am. Soc. C. E. (by letter).—Mr. Ockerson has given us a most interesting paper. The few words I shall offer refer to a single paragraph and are simply a caution that care must be taken not to draw too general conclusions from special cases when dealing with rivers, for while general principles and good common-sense in their application must govern in the improvement of them all, a careful and special adaptation of these to each particular case is vitally necessary to prevent unfortunate results.

The constitutions of rivers, if I may use such an expression, while agreeing in general conditions, differ in detail as much as those of

human beings, and when an attempt is made to cure their irregularities, care must be taken to adopt the special treatment suitable to each. The same will seldom answer for any two.

Mr. Ockerson, on page 418 of Vol. XXVIII of the *Transactions*, has the following:

"It is plainly evident that bank erosion is one of the principal factors in the solution of the problem of river improvement and control. If contraction works are built, then erosion becomes active on the opposite bank, and the river soons moves beyond the sphere of influence of such works."

He evidently had in mind the Mississippi and Missouri rivers. They are special and very grand and difficult cases. But his statement is a general one. If, instead of saying, "then erosion becomes active on the opposite side," he had said, "then a tendency to erosion becomes active on the opposite side," I should have agreed with him entirely. And I have very little doubt that he meant what I have substituted for his written words.

In order to show what I intend to imply by the foregoing, I venture to quote from a paper presented to the Society several years ago:

"On the * * * River, the arrangement of the regulating works has been arrived at in the following manner. After the surveys and maps were made and due investigation was had of the requirements of the case, the formulas told what should be the width of channel of an assumed depth and shape, which a river with the characteristics of the * * * would bear. Inasmuch, however, as a river is seldom the same creature for two successive days, and the variations of regimen in a year are large, there are, for these and other reasons, elements which cannot be accurately taken into account by the rigid rules of mathematics. In other words, the best hydraulic formulas give but approximate results. Woe to the man who follows them strictly.

"Under these circumstances, the method of improvement must be to some extent tentative. If one bank of the river is firm and the shape of the reach favorable, spurs may be run out from the other bank, gradually, to nearly the length which would be needed to give the contraction indicated by the formulas. Observation for a year or more may show the need of lengthening all the spurs, to produce the desired effect. Or it may be found they are all too long and must be cut off. Or it may be necessary to lengthen some and shorten some.

"If the bank towards which the spurs run is liable to erosion, it must be revetted, or a training wall be built in front of it. Sometimes it may be best to run spurs from both banks simultaneously. As far as injury from undermining is concerned, the danger for spurs is less

than for training walls, as only the ends of the spurs are thus exposed. When the proper length for the spurs has been determined, their ends may be connected by a longitudinal wall."

A. F. WROTNOWSKI, M. Am. Soc. C. E. (by letter).—The data incorporated in the valuable paper of Mr. Ockerson bring to mind many important features connected with this great river, whose regimen is, perhaps, considering its importance, least known, not only to the general public, but also to engineers generally, and yet it is a river whose tributaries, stretching 12 000 miles of navigation, permeate and drain the granaries of this country, and which, as a river, is, perhaps, first in importance to the commercial interests of the world. Interesting and valuable as is this paper, it is lacking much in matter to bring out a tangible value for a proper consideration of the subject. A profile of the land surface, of the high and low water-marks of the depths of the river, the slopes, abnormal width, and the wet and dry perimeter of the same, are essential for a proper study to obtain practical results.

It seems to me that the slope of the river bears largely on the development of the forces which cause the abrasions so graphically illustrated by Mr. Ockerson, and that this element should be made an important factor in determining the conditions under which the abrasions are so made. As the slope of the river determines the velocity of the current which is the force or energy causing the erosions and consequent changes, so should this element enter largely into consideration. The slight caving, for instance, as shown in the diagram, which occurs below Red River, as compared with points above, can be accounted for, in part, by the slope of the river from about Red River down to the sea, being less than one-half per mile of the slope above to Cairo.

It is also well known that bank protection and contracting the abnormal widths of the river have been carried on by the United States Government under the able management of the Mississippi River Commission for the last 12 years, and that these improvements must result in considerable influence in bettering the condition of the banks and channels, and that from the remarkable excess of caving in some localities above Red River, as compared with others under about like conditions, shows that some factors are wanting from which to deduct practical results.

J. A. OCKERSON, M. Am. Soc. C. E. (by letter).—The discussion of

this paper has brought out many interesting points in a field which is full of intricate problems which challenge the skill of the brightest minds in their solution. The gentlemen who have taken part in this discussion have drawn from their large experience, and have given us the results of their observations in a way that will add much to the value of the pages of our *Transactions*.

In the original paper the author purposely omitted the "enunciation of any dogma," and is quite willing to admit that many "columns" of valuable matter might be added to the tables. The author attempted to give a plain statement of observed facts pertaining to bank erosion. It may be well to remind Mr. Marshall and Mr. Wrotnowski that any one of the items of slope, depth, velocity, etc., would require a very extended paper in their elucidation, and there was no attempt made to cover the whole range of river physics in one paper on "bank erosion."

Mr. Richardson's statement that "a great deal of fairly accurate data as to bank erosion in the past might be obtained by comparisons with the land surveys," is correct. In the surveys made by the Mississippi River Commission it has been the rule throughout, to connect with all reliable township and section corners within the limits of the work that could be readily identified. A great many "corners" of this kind have been located, and, of course, more would be desirable, but definite information concerning them is difficult to get, and any one who has attempted to find them in the tangled brakes of the lower Mississippi will readily understand why they are not more frequent on the maps.

I am quite willing to accept Colonel Craighill's amendment and agree with him that each particular case of regulation requires special study, and often special treatment, to suit the peculiar conditions. These, however, come rather as modifications of the larger general scheme, which involves the regulation and control of the stream as a whole.

Mr. Wrotnowski falls into the common error of supposing that "the slope of the river determines the velocity of the current."

The mean velocity at high water at Hannibal, Mo., 140 miles above St. Louis, is 4.6 ft. per second, with a slope of over 0.7 ft. per mile.

At Columbus: mean velocity, 8.2 ft. per second; and slope, 0.53 ft. per mile.

At Helena: mean velocity, 6.3 ft. per second; and slope, 0.45 ft. per mile.

At Carrollton: mean velocity, 6.3 ft. per second; and slope about 0.2 ft. per mile.

So the problem is really not as simple as it would seem at first glance.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

688.

(Vol. XXXI.—January, 1894.)

STORAGE AND PONDAGE OF WATER.*

By JOSEPH P. FRIZELL, M. Am. Soc. C. E.

READ OCTOBER 4TH, 1893.

The total annual flow of a stream in Massachusetts is distributed throughout the several months, taking the average of a series of years, in about the following manner :

About	10%	comes	in the month	of January.
14	"	"	"	February.
20	"	"	"	March.
15	"	"	"	April.
10	"	"	"	May.
4	"	"	"	June.
2	"	"	"	July.
3	"	"	"	August.
3	"	"	"	September.
5	"	"	"	October.
6	"	"	"	November.
8	"	"	"	December.

*Discussions on this paper received before May 1st, 1894, will be published in a subsequent number.

This ratio of distribution is modified to some extent in other parts of New England, the time of extreme high and extreme low water being later in the northern part and earlier in the southern.

This statement exhibits in a very strong light the chief defect of water-power, viz., its extreme variability. An establishment depending wholly on water-power, which would run its machinery throughout the year without serious interruptions, cannot use more than 2% of the annual flow of the stream in any one month, or more than 24% in a year. Even with this use of water it would be exposed to more serious interruptions than appear above. In the months of August and September the flow would naturally be below the average half the time, and often below 2 per cent. In June and October, also, though the flow is 4 or 5% upon an average, there would be many days on which it would be below 3 and below 2. Moreover, the above statement represents the average of a long series of years. In such a series, years will occur with a total flow of not more than half the average, and others with nearly or quite double. Several years will occur in succession, falling 25 to 50% below the average. Others, as much above.

It results from these conditions that no rational use can be made of water-power, subject to the requirements of modern industry, without either steam-power to supply deficiencies in dry seasons, or storage reservoirs to hold back the surplus of the high-water period for use in times of scarcity. With reservoirs it is possible, though hardly ever practicable, to make use of the entire flow of the stream, reducing it to a uniform average stage throughout the entire year, or even for a series, or what may be called a cycle, of years, that is, for a period long enough to embrace all possible fluctuations of the flow. With the aid of steam-power alone it is never possible to make use of the entire product of the stream. This would imply the establishment of wheels and other appliances of water-power to the extent of the maximum flow of the stream, a proceeding obviously irrational. It is not worth while to introduce such plant to a greater extent than can be kept in operation for at least three or four months in an average year. This necessarily leaves large volumes of water to run to waste, so that the use of steam-power does not preclude the profitable use of reservoirs.

In tables which follow the writer has endeavored to compute the

value of reservoirs used in connection with steam. The several elements of this computation are :

First.—The quantity of water to be expected month by month and year by year from a given extent of drainage ground.

Second.—The quantity of steam-power required to make up the deficiencies of the water-power and maintain a constant total of power.

Third.—The change in the relative proportions of water and steam consequent upon reservoirs of different sizes.

Fourth.—The cost of steam-power.

The saving in steam-power that can be effected by reservoirs determines the amount that can be judiciously expended in their construction.

The flow from a drainage area of given extent has been observed daily by the engineers of the Boston Water Works for the last 30 years, viz., from 1863 to 1892, inclusive. These observations, previous to 1875, refer to the Cochituate drainage ground of some 16 sq. miles extent. Since that time they include the Sudbury Basin of some 75 sq. miles. These results may be applied, without serious risk of error, to any drainage area in New England.

Assume an establishment on a stream of 500 sq. miles drainage area, with a fall of 15 ft. and a requirement of 1 000 H. P., being furnished to that extent, both with water wheels and steam engines. To avoid the complication of pondage, assume the use of water to be continuous during the 24 hours. One thousand horse-power on a fall of 15 ft. requires about 800 cu. ft. per second. This is assumed as equivalent to 2 000 000 000 cu. ft. per month, which almost amounts to the supposition that the water runs to waste on Sundays and holidays.

Table No. 1 exhibits the flow of water in the natural condition of the stream, being the monthly average in cubic feet per second for the entire period of 30 years.

Table No. 2 gives the aggregate volume of water furnished each month in millions of cubic feet.

These two tables show in a marked manner the enormous fluctuations of the stream. The month of March, 1877, furnished 9 973 000 000 cu. ft.; September, only 119 000 000; the former being 3 723 cu. ft. per second; the latter, only 46. During March, assuming the flow to be uniform, 30 48-in. Rodney Hunt water wheels might have run at full gate. In September, a single wheel could hardly

have run at half gate. Other years show equally striking variations in other respects. Thus, in 1877, the highest monthly average exceeds the lowest 80 times. In 1889, the highest monthly average is only a little more than 4 times the lowest.

Table No. 3 gives the aggregate steam-power required each month to supplement the water-power, and make up a constant total of 1 000 H. P. The figures represent horse-powers 24 hours a day throughout the month.

Table No. 4 shows the effect of reservoirs of different sizes upon the quantity of water available for power. It shows, in millions of cubic feet, the volumes of water drawn from the reservoir, used and wasted, during the month, and that remaining in reservoir at the close of the month, for reservoirs of 3 000 000 000, 5 000 000 000 and 10 000 000 000 cu. ft., respectively. This table runs through the whole period of 30 years, month by month, and is necessarily voluminous.

Tables Nos. 5, 6 and 7 show, month by month, the steam-power required with reservoirs of 3 000 000 000, 5 000 000 000 and 10 000 000 000 cu. ft., respectively, expressed in Table No. 3.

Table No. 8 is a summary of the whole matter, being the cost of the steam-power each year. The first column contains the year; the second, the cost of steam-power in the natural condition of the stream; the third, the cost with reservoirs of 3 000 000 000 cu. ft.; the fourth, with 5 000 000 000; the fifth, with 10 000 000 000.

Cost of Steam-Power.—Charles E. Emery, M. Am. Soc. C. E., an engineer specially familiar with steam-power, in a carefully prepared paper presented to the Society in 1883, estimates the running cost of steam-power in engines of 500 H. P., working 10 hours a day, at $25 or $26 per annum per horse-power, the engine being supposed to run throughout the year at full load. In this estimate he puts the cost of coal at $4.17 per ton of 2 240 lbs., delivered in the coal house. This is too low for the inland towns of New England. The writer puts the cost of coal for the present purpose at $5 per ton of 2 000 lbs., delivered in coal house. This would raise the figure to $31 or $32 per annum per horse-power, or, we will say, for convenience, 10 cents per working day, or one cent per hour. This, it must be borne in mind, is for an engine running constantly at full load. An engine used to make up deficiencies of water-power, works under much less favorable conditions. It stops and starts with little notice. It works under loads varying

from a few horse-power up to nearly full capacity; most of the time, much below full capacity. Suppose, for instance, an engine of 500 H. P. to use, when running at full or nearly full load, 3 lbs. of coal per horse-power per hour. This engine, running without any load, would show, by indicator, some 50 H. P. In running to supply a deficiency of 50 H. P. it would indicate something over 100 H. P., and require 6 lbs. of coal per hour for each horse-power furnished. Moreover, wages of employees have to be paid, or their services employed in more or less unprofitable ways, while the engine is not running. For these reasons it appears that the power furnished by an engine under these conditions would cost 50% more than by one working constantly at full load. A part of this increase, however, is expense that attaches to the steam plant whether running or not, and would not appear in the sums credited to the reservoirs. The cost of the power has, therefore, been computed at 1¼ cents per hour, or 30 cents per day of 24 hours, per horse-power.

TABLE No. 1.

FLOW IN CUBIC FEET PER SECOND FROM 500 SQ. MILES OF NEW ENGLAND DRAINAGE AREA. AVERAGE FOR EACH MONTH.

	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1863.....	837	1 493	1 609	1 981	624	300	1 288	654	439	572	1 187	941
1864.....	1 036	725	1 756	1 187	702	219	178	281	220	620	560	577
1865.....	932	835	2 021	1 210	2 038	149	199	204	201	303	448	490
1866.....	316	1 363	763	730	559	493	520	278	600	403	443	676
1867.....	477	2 516	1 518	1 286	954	291	256	911	139	442	493	485
1868.....	529	519	1 665	1 559	2 676	712	195	512	848	412	878	507
1869.....	789	883	1 431	1 116	954	479	321	257	493	1 028	582	1 374
1870.....	2 042	1 887	1 466	3 079	720	434	230	178	385	481	394	334
1871.....	446	1 094	1 097	708	867	390	186	366	175	298	582	526
1872.....	498	432	611	1 380	477	667	60	572	762	733	896	524
1873.....	1 340	754	1 687	2 729	1 153	201	269	607	349	884	833	1 162
1874.....	1 539	1 051	798	1 429	1 205	878	412	399	237	225	260	221
1875.....	80	1 175	1 241	2 358	919	672	248	305	160	499	1 079	451
1876.....	497	1 058	3 431	2 547	881	171	141	313	142	181	841	351
1877.....	508	734	3 723	1 851	1 074	462	156	93	46	488	1 096	997
1878.....	1 400	1 907	2 713	1 258	1 078	391	99	367	124	399	1 306	2 458
1879.....	506	1 323	1 802	2 410	861	319	122	305	109	54	159	358
1880.....	867	1 382	1 060	904	397	136	136	92	62	78	158	135
1881.....	320	1 224	3 097	1 196	746	1 035	214	114	152	143	305	600
1882.....	959	1 859	2 196	670	1 000	409	67	43	237	231	167	243
1883.....	259	799	1 246	1 044	725	232	89	607	70	143	158	149
1884.....	770	2 198	2 928	2 222	797	322	173	198	34	64	135	715
1885.....	955	1 047	1 216	1 404	1 033	329	48	186	93	259	911	908
1886.....	1 131	3 713	1 592	1 506	557	157	89	73	91	112	520	789
1887.....	2 003	2 187	2 219	2 026	789	320	88	165	85	147	285	497
1888.....	813	1 509	2 504	2 046	1 263	326	93	293	893	1 546	2 133	2 354
1889.....	2 152	925	1 010	1 090	680	505	490	1 107	637	951	1 501	1 733
1890.....	970	1 182	2 818	1 450	1 057	438	83	102	354	1 757	940	770
1891.....	2 334	2 696	3 445	1 816	440	320	115	125	157	162	235	421
1892.....	1 446	716	1 512	674	973	331	165	217	177	97	544	375
Averages.	955	1 373	1 872	1 562	940	403	224	330	282	457	668	737

TABLE No. 2.

Flow From 500 Sq. Miles of New England Drainage Area.
Aggregate for Each Month in Millions of Cubic Feet.

	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1863.....	2 242	3 612	4 309	5 134	1 672	778	3 450	1 754	1 138	1 533	3 078	2 520
1864.....	2 776	1 812	4 704	3 078	1 882	569	476	754	569	1 661	1 452	1 545
1865.....	2 497	2 021	5 413	3 137	5 459	395	534	546	522	813	1 161	1 312
1866.....	848	3 299	2 044	1 893	1 498	1 267	1 394	743	1 556	1 080	1 150	1 812
1867.....	1 277	6 086	4 065	3 334	2 555	755	685	2 439	360	1 185	1 277	1 301
1868.....	1 417	1 301	4 460	4 042	7 167	1 847	522	1 370	2 149	1 103	2 276	1 359
1869.....	2 114	2 137	3 833	2 892	2 555	1 243	859	673	1 277	2 753	1 510	3 682
1870.....	5 471	4 565	3 926	7 980	1 928	1 126	615	476	999	1 289	1 022	894
1871.....	1 196	2 648	2 939	1 835	2 323	1 010	499	987	453	801	1 510	1 409
1872.....	1 336	1 080	1 638	3 577	1 277	1 731	162	1 533	1 974	1 963	2 323	1 405
1873.....	3 589	1 823	4 518	7 074	3 090	522	720	1 626	906	2 369	2 160	3 113
1874.....	4 123	2 544	2 137	3 705	3 229	2 276	1 103	1 068	615	604	673	592
1875.....	213	2 800	3 324	6 113	2 461	1 743	665	820	416	1 338	2 611	1 209
1876.....	1 332	2 651	9 189	6 602	2 359	445	378	840	369	484	2 181	939
1877.....	1 363	1 776	9 973	4 799	2 883	1 197	418	251	119	1 309	2 842	2 671
1878.....	3 749	4 614	7 267	3 260	2 889	1 014	266	985	322	1 070	3 394	6 583
1879.....	1 451	3 201	4 827	6 248	2 308	828	326	819	282	146	412	958
1880.....	2 323	3 464	2 847	2 343	1 065	352	366	246	160	210	411	362
1881.....	859	2 893	8 296	3 100	1 999	2 682	572	306	395	384	792	1 606
1882.....	2 570	4 497	5 882	1 738	2 676	1 060	179	115	614	619	420	651
1883.....	693	1 933	3 337	2 706	1 943	601	239	1 626	182	384	411	400
1884.....	2 062	5 508	7 843	5 721	2 135	835	463	532	88	172	351	1 916
1885.....	2 559	2 533	3 258	3 639	2 768	854	129	498	243	696	2 361	2 342
1886.....	3 027	8 984	4 265	3 904	1 492	406	239	195	236	302	1 348	2 113
1887.....	5 365	5 291	5 942	5 253	2 089	829	237	443	222	393	739	1 332
1888.....	2 181	3 781	6 708	5 304	3 382	845	243	786	2 316	4 142	5 530	6 305
1889.....	5 765	2 237	2 774	2 827	1 822	1 310	1 312	2 966	1 682	2 548	3 892	4 643
1890.....	2 598	2 861	7 548	3 759	2 831	1 138	222	273	917	4 708	2 436	2 063
1891.....	6 253	6 523	9 227	4 806	1 207	829	309	337	406	435	611	1 128
1892.....	3 874	1 793	4 051	1 747	2 608	858	443	581	460	260	1 398	1 005
Averages.	2 571	3 342	5 018	4 052	2 518	1 045	601	886	730	1 225	1 724	1 974

TABLE No. 3.

STEAM-POWER REQUIRED TO MAKE UP A UNIFORM TOTAL OF 1 000 H. P. 24 HOURS A DAY IN A MILL COMMANDING 500 SQ. MILES OF NEW ENGLAND DRAINAGE AREA. WITHOUT RESERVOIRS. HEAD 15 FT. POWER EXPRESSED IN HORSE-POWER 24 HOURS A DAY.

	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1863	.....	.....	.....	.....	164	611	.....	123	431	233	.....	.....
1864	.....	94	.....	.....	59	716	762	623	716	170	274	228
1865	.....	.....	.....	.....	.....	803	733	727	739	594	420	344
1866	576	.....	.....	54	261	367	303	629	222	460	425	94
1867	362	.....	.....	.....	.....	623	658	.....	820	408	362	350
1868	292	350	.....	.....	.....	77	739	315	.....	449	.....	321
1869	.....	.....	.....	.....	.....	379	571	664	362	.....	245	.....
1870	.....	.....	.....	.....	36	436	693	762	500	356	489	553
1871	402	.....	.....	83	.....	495	751	507	774	600	245	296
1872	332	460	181	.....	362	135	919	234	13	19	.....	298
1873	.....	89	.....	.....	.....	739	640	187	547	.....	.....	.....
1874	.....	.....	.....	.....	.....	.....	449	466	693	698	664	704
1875	894	.....	.....	.....	.....	129	668	590	792	331	.....	396
1876	334	.....	.....	.....	.....	778	811	580	816	758	.....	531
1877	319	112	.....	.....	.....	402	791	875	941	346	.....	.....
1878	.....	.....	.....	.....	.....	493	867	508	839	465	.....	.....
1879	275	.....	.....	.....	.....	586	837	591	859	927	794	521
1880	.....	.....	.....	.....	468	824	817	877	920	895	795	819
1881	571	.....	.....	.....	.....	.....	714	847	803	808	604	197
1882	.....	.....	.....	131	.....	470	911	943	693	691	790	675
1883	654	34	.....	.....	29	700	881	187	909	808	795	800
1884	.....	.....	.....	.....	.....	583	769	734	956	914	825	42
1885	.....	.....	.....	.....	.....	573	936	751	879	652	.....	.....
1886	.....	.....	.....	.....	254	797	881	903	882	849	326	.....
1887	.....	.....	.....	.....	.....	586	882	779	889	804	631	334
1888	.....	.....	.....	.....	.....	578	879	607	.....	.....	.....	.....
1889	.....	.....	.....	.....	89	345	344	.....	174	.....	.....	.....
1890	.....	.....	.....	.....	.....	431	889	864	542	.....	.....	.....
1891	.....	.....	.....	.....	397	586	846	832	797	783	695	436
1892	.....	104	.....	127	.....	571	779	710	770	870	301	498

TABLE No. 4.

EFFECT OF RESERVOIRS OF DIFFERENT SIZES UPON THE FLOW OF 500 SQ. MILES OF NEW ENGLAND DRAINAGE AREA, FROM 1863 TO 1892. QUANTITIES IN MILLIONS OF CUBIC FEET.

CAPACITY OF RESERVOIR.	3 000 000 000.				5 000 000 000.				10 000 000 000.			
	Drawn from reservoir.	Used.	Wasted.	In reservoir at end of month.	Drawn from reservoir.	Used.	Wasted.	In reservoir at end of month.	Drawn from reservoir.	Used.	Wasted.	In reservoir at end of month.
1863. January	.....	2 000	.....	242	.....	2 000	.....	242	.....	2 000	.....	242
February	.....	2 000	.....	1 854	.....	2 000	.....	1 854	.....	2 000	.....	1 854
March	.....	2 000	1 163	3 000	.....	2 000	.....	4 163	.....	2 000	.....	4 163
April	.....	2 000	3 134	3 000	.....	2 000	2 297	5 000	.....	2 000	.....	7 297
May	328	2 000	.....	2 672	328	2 000	.....	4 672	328	2 000	.....	6 969
June	1 222	2 000	.....	1 450	1 222	2 000	.....	3 450	1 222	2 000	.....	5 747
July	.....	2 000	.....	2 900	.....	2 000	.....	4 900	.....	2 000	.....	7 197
August	246	2 000	.....	2 654	246	2 000	.....	4 654	246	2 000	.....	6 951
September	862	2 000	.....	1 792	862	2 000	.....	3 792	862	2 000	.....	6 089
October	467	2 000	.....	1 325	467	2 000	.....	3 325	467	2 000	.....	5 622
November	.....	2 000	.....	2 403	.....	2 000	.....	4 403	.....	2 000	.....	6 700
December	.....	2 000	.....	2 923	.....	2 000	.....	4 923	.....	2 000	.....	7 220
1864. January	.....	2 000	699	3 000	.....	2 000	699	5 000	.....	2 000	.....	7 996
February	188	2 000	.....	2 812	188	2 000	.....	4 812	188	2 000	.....	7 808
March	.....	2 000	2 516	3 000	.....	2 000	2 516	5 000	.....	2 000	512	10 000
April	.....	2 000	1 078	3 000	.....	2 000	1 078	5 000	.....	2 000	1 078	10 000
May	118	2 000	.....	2 882	118	2 000	.....	4 882	118	2 000	.....	9 882
June	1 431	2 000	.....	1 451	1 431	2 000	.....	3 451	1 431	2 000	.....	8 451
July	1 451	1 927	.....	0	1 524	2 000	.....	1 927	1 524	2 000	.....	6 927
August	.....	754	.....	0	1 246	2 000	.....	681	1 246	2 000	.....	5 681
September	.....	569	.....	0	681	1 250	.....	0	1 431	2 000	.....	4 250
October	.....	1 661	.....	0	.....	1 661	.....	0	339	2 000	.....	3 911
November	.....	1 452	.....	0	.....	1 452	.....	0	548	2 000	.....	3 363
December	.....	1 545	.....	0	.....	1 545	.....	0	455	2 000	.....	2 908
1865. January	.....	2 000	.....	497	.....	2 000	.....	497	.....	2 000	.....	3 405
February	.....	2 000	.....	518	.....	2 000	.....	518	.....	2 000	.....	3 426
March	.....	2 000	931	3 000	.....	2 000	.....	3 931	.....	2 000	.....	6 039
April	.....	2 000	1 137	3 000	.....	2 000	68	5 000	.....	2 000	.....	7 776
May	.....	2 000	3 459	3 000	.....	2 000	3 459	5 000	.....	2 000	1 235	10 000
June	1 605	2 000	.....	1 395	1 605	2 000	.....	3 395	1 605	2 000	.....	8 395
July	1 395	1 929	.....	0	1 466	2 000	.....	1 929	1 466	2 000	.....	6 929
August	.....	546	.....	0	1 454	2 000	.....	475	1 454	2 000	.....	5 475
September	.....	522	.....	0	475	997	.....	0	1 478	2 000	.....	3 997
October	.....	813	.....	0	.....	813	.....	0	1 187	2 000	.....	2 810
November	.....	1 161	.....	0	.....	1 161	.....	0	839	2 000	.....	1 971
December	.....	1 312	.....	0	.....	1 312	.....	0	688	2 000	.....	1 283
1866. January	.....	848	.....	0	.....	848	.....	0	1 152	2 000	.....	131
February	.....	2 000	.....	1 299	.....	2 000	.....	1 299	.....	2 000	.....	1 430
March	.....	2 000	.....	1 343	.....	2 000	.....	1 343	.....	2 000	.....	1 474
April	107	2 000	.....	1 236	107	2 000	.....	1 236	107	2 000	.....	1 367
May	502	2 000	.....	734	502	2 000	.....	734	502	2 000	.....	865
June	733	2 000	.....	1	733	2 000	.....	1	733	2 000	.....	132
July	1	395	.....	0	1	395	.....	0	132	1 526	.....	0
August	.....	743	.....	0	.....	743	.....	0	.....	743	.....	0
September	.....	1 556	.....	0	.....	1 556	.....	0	.....	1 556	.....	0
October	.....	1 080	.....	0	.....	1 080	.....	0	.....	1 080	.....	0
November	.....	1 150	.....	0	.....	1 150	.....	0	.....	1 150	.....	0
December	.....	1 812	.....	0	.....	1 812	.....	0	.....	1 812	.....	0

TABLE No. 4—(*Continued*).

Capacity of Reservoir.	3 000 000 000.				5 000 000 000.				10 000 000 000.			
	Drawn from reservoir.	Used.	Wasted.	In reservoir at end of month.	Drawn from reservoir.	Used.	Wasted.	In reservoir at end of month.	Drawn from reservoir.	Used.	Wasted.	In reservoir at end of month.
1867. January	.....	1 277	.....	0	.....	1 277	.....	0	.....	1 277	.....	0
February	.....	2 000	1 086	3 000	.....	2 000	.....	4 086	.....	2 000	.....	4 086
March	.....	2 000	2 065	3 000	.....	2 000	1 151	5 000	.....	2 000	.....	6 151
April	.....	2 000	1 334	3 000	.....	2 000	1 334	5 000	.....	2 000	.....	7 485
May	.....	2 000	555	3 000	.....	2 000	555	5 000	.....	2 000	.....	8 040
June	1 245	2 000	.....	1 755	1 245	2 000	.....	3 755	1 245	2 000	.....	6 795
July	1 315	2 000	.....	440	1 315	2 000	.....	2 440	1 315	2 000	.....	5 480
August	.....	2 000	.....	879	.....	2 000	.....	2 879	.....	2 000	.....	5 919
September	879	1 239	.....	0	1 640	2 000	.....	1 239	1 640	2 000	.....	4 279
October	.....	1 185	.....	0	815	2 000	.....	424	815	2 000	.....	3 464
November	.....	1 277	.....	0	424	1 701	.....	0	723	2 000	.....	2 741
December	.....	1 301	.....	0	.....	1 301	.....	0	699	2 000	.....	2 042
1868. January	.....	1 417	.....	0	.....	1 417	.....	0	583	2 000	.....	1 459
February	.....	1 301	.....	0	.....	1 301	.....	0	699	2 000	.....	760
March	.....	2 000	.....	2 460	.....	2 000	.....	2 460	.....	2 000	.....	3 220
April	.....	2 000	1 502	3 000	.....	2 000	.....	4 502	.....	2 000	.....	5 262
May	.....	2 000	5 167	3 000	.....	2 000	4 669	5 000	.....	2 000	429	10 000
June	153	2 000	.....	2 847	153	2 000	.....	4 847	153	2 000	.....	9 847
July	1 478	2 000	.....	1 369	1 478	2 000	.....	3 369	1 478	2 000	.....	8 369
August	630	2 000	.....	739	630	2 000	.....	2 739	630	2 000	.....	7 739
September	.....	2 000	.....	888	.....	2 000	.....	2 888	.....	2 000	.....	7 888
October	888	1 991	.....	0	897	2 000	.....	1 991	897	2 000	.....	6 991
November	.....	2 000	.....	276	.....	2 000	.....	2 267	.....	2 000	.....	7 267
December	276	1 635	.....	0	641	2 000	.....	1 626	641	2 000	.....	6 626
1869. January	.....	2 000	.....	114	.....	2 000	.....	1 740	.....	2 000	.....	6 740
February	.....	2 000	.....	251	.....	2 000	.....	1 877	.....	2 000	.....	6 877
March	.....	2 000	.....	2 084	.....	2 000	.....	3 710	.....	2 000	.....	8 710
April	.....	2 000	.....	2 976	.....	2 000	.....	4 602	.....	2 000	.....	9 602
May	.....	2 000	531	3 000	.....	2 000	157	5 000	.....	2 000	157	10 000
June	757	2 000	.....	2 243	757	2 000	.....	4 243	757	2 000	.....	9 243
July	1 141	2 000	.....	1 102	1 141	2 000	.....	3 102	1 141	2 000	.....	8 102
August	1 102	1 675	.....	0	1 327	2 000	.....	1 775	1 327	2 000	.....	6 775
September	.....	1 277	.....	0	723	2 000	.....	1 052	723	2 000	.....	6 052
October	.....	2 000	.....	753	.....	2 000	.....	1 805	.....	2 000	.....	6 805
November	490	2 000	.....	263	.....	2 000	.....	1 315	490	2 000	.....	6 315
December	.....	2 000	.....	1 945	.....	2 000	.....	2 997	.....	2 000	.....	7 997
1870. January	.....	2 000	2 416	3 000	.....	2 000	1 468	5 000	.....	2 000	1 468	10 000
February	.....	2 000	2 565	3 000	.....	2 000	2 565	5 000	.....	2 000	2 565	10 000
March	.....	2 000	1 926	3 000	.....	2 000	1 926	5 000	.....	2 000	1 926	10 000
April	.....	2 000	5 980	3 000	.....	2 000	5 980	5 000	.....	2 000	5 980	10 000
May	72	2 000	.....	2 928	72	2 000	.....	4 928	72	2 000	.....	9 928
June	874	2 000	.....	2 054	874	2 000	.....	4 054	874	2 000	.....	9 054
July	1 385	2 000	.....	669	1 385	2 000	.....	2 669	1 385	2 000	.....	7 679
August	669	1 145	.....	0	1 524	2 000	.....	1 145	1 524	2 000	.....	6 145
September	.....	999	.....	0	1 001	2 000	.....	144	1 001	2 000	.....	5 144
October	.....	1 289	.....	0	144	1 433	.....	0	711	2 000	.....	4 435
November	.....	1 022	.....	0	.....	1 022	.....	0	978	2 000	.....	3 455
December	.....	894	.....	0	.....	894	.....	0	1 106	2 000	.....	2 349
1871. January	.....	1 196	.....	0	.....	1 196	.....	0	804	2 000	.....	1 545
February	.....	2 000	.....	648	.....	2 000	.....	648	.....	2 000	.....	2 193
March	.....	2 000	.....	1 587	.....	2 000	.....	1 587	.....	2 000	.....	3 132
April	165	2 000	.....	1 422	165	2 000	.....	1 422	165	2 000	.....	2 967
May	.....	2 000	.....	1 745	.....	2 000	.....	1 745	.....	2 000	.....	3 290
June	990	2 000	.....	755	990	2 000	.....	755	990	2 000	.....	2 300
July	755	1 254	.....	0	755	1 254	.....	0	1 501	2 000	.....	799
August	.....	987	.....	0	.....	987	.....	0	799	1 786	.....	0

TABLE No. 4—(*Continued*).

Capacity of Reservoir.	3 000 000 000.				5 000 000 000.				10 000 000 000.			
	Drawn from reservoir.	Used.	Wasted.	In reservoir at end of month.	Drawn from reservoir.	Used.	Wasted.	In reservoir at end of month.	Drawn from reservoir.	Used.	Wasted.	In reservoir at end of month.
1871. September	.....	453	.....	0	.....	453	.....	0	.....	453	.....	0
October	.....	801	.....	0	.....	801	.....	0	.....	801	.....	0
November	.....	1 510	.....	0	.....	1 510	.....	0	.....	1 510	.....	0
December	.....	1 409	.....	0	.....	1 409	.....	0	.....	1 409	.....	0
1872. January	.....	1 336	.....	0	.....	1 332	.....	0	.....	1 336	.....	0
February	.....	1 080	.....	0	.....	1 080	.....	0	.....	1 080	.....	0
March	.....	1 638	.....	0	.....	1 638	.....	0	.....	1 638	.....	0
April	.....	2 000	.....	1 577	.....	2 000	.....	1 577	.....	2 000	.....	1 577
May	723	2 000	.....	854	723	2 000	.....	854	723	2 000	.....	854
June	269	2 000	.....	585	269	2 000	.....	585	269	2 000	.....	585
July	585	747	.....	0	585	747	.....	0	585	747	.....	0
August	.....	1 533	.....	0	.....	1 533	.....	0	.....	1 533	.....	0
September	.....	1 974	.....	0	.....	1 974	.....	0	.....	1 974	.....	0
October	.....	1 963	.....	0	.....	1 963	.....	0	.....	1 963	.....	0
November	.....	2 000	.....	323	.....	2 000	.....	323	.....	2 000	.....	323
December	323	1 728	.....	0	323	1 728	.....	0	323	1 728	.....	0
1873. January	.....	2 000	.....	1 589	.....	2 000	.....	1 589	.....	2 000	.....	1 589
February	177	2 000	.....	1 412	177	2 000	.....	1 412	177	2 000	.....	1 412
March	.....	2 000	930	3 000	.....	2 000	.....	3 930	.....	2 000	.....	3 930
April	.....	2 000	5 074	3 000	.....	2 000	4 004	5 000	.....	2 000	.....	9 004
May	.....	2 000	1 090	3 000	.....	2 000	1 090	5 000	.....	2 000	94	10 000
June	1 478	2 000	.....	1 522	1 478	2 000	.....	3 522	1 478	2 000	.....	8 522
July	1 280	2 000	.....	242	1 280	2 000	.....	2 242	1 280	2 000	.....	7 242
August	.....	1 868	.....	0	374	2 000	.....	1 868	374	2 000	.....	6 868
September	.....	906	.....	0	1 094	2 000	.....	774	1 094	2 000	.....	5 774
October	.....	2 000	.....	369	.....	2 000	.....	1 143	.....	2 000	.....	6 143
November	.....	2 000	.....	529	.....	2 000	.....	1 303	.....	2 000	.....	6 303
December	.....	2 000	.....	1 642	.....	2 000	.....	2 416	.....	2 000	.....	7 416
1874. January	.....	2 000	765	3 000	.....	2 000	.....	4 539	.....	2 000	.....	9 539
February	.....	2 000	544	3 000	.....	2 000	83	5 000	.....	2 000	83	10 000
March	.....	2 000	137	3 000	.....	2 000	137	5 000	.....	2 000	137	10 000
April	.....	2 000	1 705	3 000	.....	2 000	1 705	5 000	.....	2 000	1 705	10 000
May	.....	2 000	1 229	3 000	.....	2 000	1 229	5 000	.....	2 000	1 229	10 000
June	.....	2 000	276	3 000	.....	2 000	276	5 000	.....	2 000	276	10 000
July	897	2 000	.....	2 103	897	2 000	.....	4 103	897	2 000	.....	9 103
August	932	2 000	.....	1 171	932	2 000	.....	3 171	932	2 000	.....	8 171
September	1 171	1 786	.....	0	1 385	2 000	.....	1 786	1 385	2 000	.....	6 786
October	.....	604	.....	0	1 396	2 000	.....	390	1 396	2 000	.....	5 390
November	.....	673	.....	0	390	1 063	.....	0	1 327	2 000	.....	4 063
December	.....	592	.....	0	.....	592	.....	0	1 408	2 000	.....	2 655
1875. January	.....	213	.....	0	.....	213	.....	0	.....	2 000	.....	868
February	.....	2 000	.....	800	.....	2 000	.....	800	.....	2 000	.....	1 668
March	.....	2 000	.....	2 124	.....	2 000	.....	2 124	.....	2 000	.....	2 992
April	.....	2 000	3 237	3 000	.....	2 000	1 237	5 000	.....	2 000	.....	7 105
May	.....	2 000	461	3 000	.....	2 000	461	5 000	.....	2 000	.....	7 536
June	257	2 000	.....	2 743	257	2 000	.....	4 743	257	2 000	.....	7 309
July	1 335	2 000	.....	1 408	1 335	2 000	.....	3 408	1 335	2 000	.....	5 974
August	1 180	2 000	.....	228	1 180	2 000	.....	2 228	1 180	2 000	.....	4 794
September	228	644	.....	0	1 584	2 000	.....	644	1 584	2 000	.....	3 210
October	.....	1 338	.....	0	644	1 982	.....	0	662	2 000	.....	2 548
November	.....	2 000	.....	611	.....	2 000	.....	611	.....	2 000	.....	3 159
December	611	1 820	.....	0	611	1 820	.....	0	791	2 000	.....	2 338
1876. January	.....	1 332	.....	0	.....	1 332	.....	0	668	2 000	.....	1 700
February	.....	2 000	.....	651	.....	2 000	.....	651	.....	2 000	.....	2 351
March	.....	2 000	4 840	3 000	.....	2 000	2 840	5 000	.....	2 000	.....	9 540

TABLE No. 4—(*Continued*).

Capacity of Reservoir.	3 000 000 000.				5 000 000 000.				10 000 000 000.			
	Drawn from reservoir.	Used.	Wasted.	In reservoir at end of month.	Drawn from reservoir.	Used.	Wasted.	In reservoir at end of month.	Drawn from reservoir.	Used.	Wasted.	In reservoir at end of month.
1876. April	.....	2 000	4 602	3 000	.....	2 000	4 602	5 000	.....	2 000	4 142	10 000
May	.....	2 000	359	3 000	.....	2 000	359	5 000	.....	2 000	359	10 000
June	1 555	2 000	.....	1 445	1 555	2 000	.....	3 445	1 555	2 000	.....	8 445
July	1 445	1 823	.....	0	1 622	2 000	.....	1 823	1 622	2 000	.....	6 823
August	.....	840	.....	0	1 160	2 000	.....	663	1 160	2 000	.....	5 663
September	.....	369	.....	0	663	1 032	.....	0	1 631	2 000	.....	4 032
October	.....	484	.....	0	.....	484	.....	0	1 516	2 000	.....	2 516
November	.....	2 000	.....	181	.....	2 000	.....	181	.....	2 000	.....	2 697
December	181	1 120	.....	0	181	1 120	.....	0	1 061	2 000	.....	1 636
1877. January	.....	1 363	.....	0	.....	1 363	.....	0	637	2 000	.....	999
February	.....	1 776	.....	0	.....	1 776	.....	0	224	2 000	.....	775
March	.....	2 000	4 973	3 000	.....	2 000	2 973	5 000	.....	2 000	.....	8 748
April	.....	2 000	2 799	3 000	.....	2 000	2 799	5 000	.....	2 000	1 547	10 000
May	.....	2 000	883	3 000	.....	2 000	883	5 000	.....	2 000	883	10 000
June	803	2 000	.....	2 197	803	2 000	.....	4 197	803	2 000	.....	9 197
July	1 582	2 000	.....	615	1 582	2 000	.....	2 615	1 582	2 000	.....	7 615
August	615	1 366	.....	0	1 749	2 000	.....	866	1 749	2 000	.....	5 866
September	.....	119	.....	0	866	985	.....	0	1 881	2 000	.....	3 985
October	.....	1 309	.....	0	.....	1 309	.....	0	691	2 000	.....	3 294
November	.....	2 000	.....	842	.....	2 000	.....	842	.....	2 000	.....	4 136
December	.....	2 000	.....	1 513	.....	2 000	.....	1 513	.....	2 000	.....	4 807
1878. January	.....	2 000	262	3 000	.....	2 000	.....	3 262	.....	2 000	.....	6 556
February	.....	2 000	2 614	3 000	.....	2 000	876	5 000	.....	2 000	.....	9 170
March	.....	2 000	5 267	3 000	.....	2 000	5 267	5 000	.....	2 000	4 437	10 000
April	.....	2 000	1 260	3 000	.....	2 000	1 260	5 000	.....	2 000	1 260	10 000
May	.....	2 000	889	3 000	.....	2 000	889	5 000	.....	2 000	889	10 000
June	986	2 000	.....	2 014	986	2 000	.....	4 014	986	2 000	.....	9 014
July	1 734	2 000	.....	280	1 734	2 000	.....	2 280	1 734	2 000	.....	7 280
August	280	1 265	.....	0	1 015	2 000	.....	1 265	1 015	2 000	.....	6 265
September	....	322	.....	0	1 265	1 587	.....	0	1 678	2 000	.....	4 587
October	.....	1 070	.....	0	.....	1 070	.....	0	930	2 000	.....	3 657
November	.....	2 000	.....	1 394	.....	2 000	.....	1 394	.....	2 000	.....	5 051
December	.....	2 000	2 977	3 000	.....	2 000	977	5 000	.....	2 000	.....	9 634
1879. January	549	2 000	.....	2 451	549	2 000	.....	4 451	549	2 000	.....	9 085
February	.....	2 000	652	3 000	.....	2 000	652	5 000	.....	2 000	286	10 000
March	.....	2 000	2 827	3 000	.....	2 000	2 827	5 000	.....	2 000	2 827	10 000
April	.....	2 000	4 248	3 000	.....	2 000	4 248	5 000	.....	2 000	4 248	10 000
May	.....	2 000	308	3 000	.....	2 000	308	5 000	.....	2 000	308	10 000
June	1 172	2 000	.....	1 828	1 172	2 000	.....	3 828	1 172	2 000	.....	8 828
July	1 674	2 000	.....	154	1 674	2 000	.....	2 154	1 674	2 000	.....	7 154
August	154	973	.....	0	181	2 000	.....	973	1 181	2 000	.....	5 973
September	.....	282	.....	0	973	1 255	.....	0	1 718	2 000	.....	4 255
October	.....	146	.....	0	.....	146	.....	0	1 854	2 000	.....	2 401
November	.....	412	.....	0	.....	412	.....	0	1 588	2 000	.....	813
December	.....	958	.....	0	.....	958	.....	0	813	1 771	.....	0
1880. January	.....	2 000	.....	323	.....	2 000	.....	323	.....	2 000	.....	323
February	.....	2 000	.....	1 787	.....	2 000	.....	1 787	.....	2 000	.....	1 787
March	.....	2 000	.....	2 634	.....	2 000	.....	2 634	.....	2 000	.....	2 634
April	.....	2 000	.....	2 977	.....	2 000	.....	2 977	.....	2 000	.....	2 977
May	935	2 000	.....	2 042	935	2 000	.....	2 042	935	2 000	.....	2 042
June	1 648	2 000	.....	394	1 648	2 000	.....	394	1 648	2 000	.....	394
July	394	760	.....	0	394	760	.....	0	394	760	...	0
August	.....	246	.....	0	.....	246	.....	0	.....	246	.....	0
September	.....	160	.....	0	.....	160	.....	0	.....	160	.....	0
October	.....	210	.....	0	.....	210	.....	0	.....	210	.....	0

TABLE No. 4—(*Continued*).

Capacity of Reservoir.		3 000 000 000.				5 000 000 000.				10 000 000 000.			
		Drawn from reservoir.	Used.	Wasted.	In reservoir at end of month.	Drawn from reservoir.	Used.	Wasted.	In reservoir at end of month.	Drawn from reservoir.	Used.	Wasted.	In reservoir at end of month.
1880.	November	.....	411	.....	0	.....	411	.....	0	.....	411	.....	0
	December	.....	362	.....	0	.....	362	.....	0	.....	362	.....	0
1881.	January	.....	859	.....	0	.....	859	.....	0	.....	859	.....	0
	February	.....	2 000	.....	893	.....	2 000	.....	893	.....	2 000	.....	893
	March	.....	2 000	4 189	3 000	.....	2 000	2 189	5 000	.....	2 000	.....	7 189
	April	.....	2 000	1 100	3 000	.....	2 000	1 100	5 000	.....	2 000	.....	8 289
	May	1	2 000	.....	2 999	1	2 000	.....	4 999	1	2 000	.....	8 288
	June	.....	2 000	681	3 000	.....	2 000	681	5 000	.....	2 000	.....	8 970
	July	1 428	2 000	.....	1 572	1 428	2 000	.....	3 572	1 428	2 000	.....	7 542
	August	1 572	1 878	.....	0	1 694	2 000	.....	1 878	1 694	2 000	.....	5 848
	September	.....	395	.....	0	1 605	2 000	.....	273	1 605	2 000	.....	4 243
	October	.....	384	.....	0	273	657	.....	0	1 616	2 000	.....	2 627
	November	.....	792	.....	0	.....	792	.....	0	1 208	2 000	.....	1 419
	December	.....	1 606	.....	0	.....	1 606	.....	0	394	2 000	.....	1 025
1882.	January	.....	2 000	.....	570	.....	2 000	.....	570	.....	2 000	.....	1 595
	February	.....	2 000	67	3 000	.....	2 000	.....	3 067	.....	2 000	.....	4 092
	March	.....	2 000	3 882	3 000	.....	2 000	1 949	5 000	.....	2 000	.....	7 974
	April	262	2 000	.....	2 738	262	2 000	.....	4 738	262	2 000	.....	7 712
	May	.....	2 000	414	3 000	.....	2 000	414	5 000	.....	2 000	.....	8 388
	June	940	2 000	.....	2 060	940	2 000	.....	4 060	940	2 000	.....	7 448
	July	1 821	2 000	.....	239	1 821	2 000	.....	2 239	1 821	2 000	.....	5 627
	August	239	354	.....	0	1 885	2 000	.....	354	1 885	2 000	.....	3 742
	September	.....	614	.....	0	354	968	.....	0	1 386	2 000	.....	2 356
	October	.....	619	.....	0	.....	619	.....	0	1 381	2 000	.....	975
	November	.....	420	.....	0	.....	420	.....	0	975	1 395	.....	0
	December	.....	651	.....	0	.....	651	.....	0	.....	651	.....	0
1883.	January	.....	693	.....	0	.....	693	.....	0	.....	693	.....	0
	February	.....	1 933	.....	0	.....	1 933	.....	0	.....	1 933	.....	0
	March	.....	2 000	.....	1 337	.....	2 000	.....	1 337	.....	2 000	.....	1 337
	April	.....	2 000	.....	2 043	.....	2 000	.....	2 043	.....	2 000	.....	2 043
	May	57	2 000	.....	1 986	57	2 000	.....	1 986	57	2 000	.....	1 986
	June	1 399	2 000	.....	587	1 399	2 000	.....	587	1 399	2 000	.....	587
	July	587	826	.....	0	587	826	.....	0	587	826	.....	0
	August	.....	1 626	.....	0	.....	1 626	.....	0	.....	1 626	.....	0
	September	.....	182	.....	0	.....	182	.....	0	.....	182	.....	0
	October	.....	384	.....	0	.....	384	.....	0	.....	384	.....	0
	November	.....	411	.....	0	.....	411	.....	0	.....	411	.....	0
	December	.....	400	.....	0	.....	400	.....	0	.....	400	.....	0
1884.	January	.....	2 000	.....	62	.....	2 000	.....	62	.....	2 000	.....	62
	February	.....	2 000	570	3 000	.....	2 000	.....	3 570	.....	2 000	.....	3 570
	March	.....	2 000	5 843	3 000	.....	2 000	4 413	5 000	.....	2 000	.....	9 413
	April	.....	2 000	3 721	3 000	.....	2 000	3 721	5 000	.....	2 000	3 134	10 000
	May	.....	2 000	135	3 000	.....	2 000	135	5 000	.....	2 000	135	10 000
	June	1 165	2 000	.....	1 835	1 165	2 000	.....	3 835	1 165	2 000	.....	8 835
	July	1 537	2 000	.....	298	1 537	2 000	.....	2 298	1 537	2 000	.....	7 298
	August	298	830	.....	0	1 468	2 000	.....	830	1 468	2 000	.....	5 830
	September	.....	88	.....	0	830	918	.....	0	1 912	2 000	.....	3 918
	October	.....	172	.....	0	.....	172	.....	0	1 828	2 000	.....	2 090
	November	.....	351	.....	0	.....	351	.....	0	1 649	2 000	.....	441
	December	.....	1 916	.....	0	.....	1 916	.....	0	84	2 000	.....	357
1885.	January	.....	2 000	.....	559	.....	2 000	.....	559	.....	2 000	.....	916
	February	.....	2 000	.....	1 092	.....	2 000	.....	1 092	.....	2 000	.....	1 449
	March	.....	2 000	.....	2 350	.....	2 000	.....	2 350	.....	2 000	.....	2 707
	April	.....	2 000	989	3 000	.....	2 000	.....	3 989	.....	2 000	.....	4 346
	May	.....	2 000	768	3 000	.....	2 000	.....	4 757	.....	2 000	.....	5 114

TABLE No. 4—(*Continued*).

Capacity of Reservoir.	3 000 000 000.				5 000 000 000.				10 000 000 000.			
	Drawn from reservoir.	Used.	Wasted.	In reservoir at end of month.	Drawn from reservoir.	Used.	Wasted.	In reservoir at end of month.	Drawn from reservoir.	Used.	Wasted.	In reservoir at end of month.
1885. June	1 146	2 000	.....	1 854	1 146	2 000	.....	3 611	1 146	2 000	.....	3 968
July	1 854	1 983	.....	0	1 871	2 000	.....	1 740	1 871	2 000	.....	2 097
August	.....	498	.....	0	1 502	2 000	.....	238	1 502	2 000	.....	595
September	.....	243	.....	0	238	481	.....	0	595	838	.....	0
October	.....	696	.....	0	.....	696	.....	0	.....	696	.....	0
November	.....	2 000	.....	361	.....	2 000	.....	361	.....	2 000	.....	361
December	.....	2 000	.....	703	.....	2 000	.....	703	.....	2 000	.....	703
1886. January	.....	2 000	.....	1 730	.....	2 000	.....	1 730	.....	2 000	.....	1 730
February	.....	2 000	5 714	3 000	.....	2 000	3 714	5 000	.....	2 000	.....	8 714
March	.....	2 000	2 265	3 000	.....	2 000	2 265	5 000	.....	2 000	979	10 000
April	.....	2 000	1 904	3 000	.....	2 000	1 904	5 000	.....	2 000	1 904	10 000
May	508	2 000	.....	2 492	508	2 000	.....	4 492	508	2 000	.....	9 492
June	1 594	2 000	.....	898	1 594	2 000	.....	2 898	1 594	2 000	.....	7 898
July	898	1 137	.....	0	1 761	2 000	.....	1 137	1 761	2 000	.....	6 137
August	.....	195	.....	0	1 137	1 332	.....	0	1 805	2 000	.....	4 332
September	.....	236	.....	0	.....	236	.....	0	1 764	2 000	.....	2 568
October	.....	302	.....	0	.....	302	.....	0	1 698	2 000	.....	870
November	.....	1 348	.....	0	.....	1 348	.....	0	652	2 000	.....	218
December	.....	2 000	.....	113	.....	2 000	.....	113	.....	2 000	.....	331
1887. January	.....	2 000	478	3 000	.....	2 000	.....	3 478	.....	2 000	.....	3 696
February	.....	2 000	3 291	3 000	.....	2 000	1 769	5 000	.....	2 000	.....	6 987
March	.....	2 000	3 942	3 000	.....	2 000	3 942	5 000	.....	2 000	929	10 000
April	.....	2 000	3 253	3 000	.....	2 000	3 253	5 000	.....	2 000	3 253	10 000
May	.....	2 000	89	3 000	.....	2 000	89	5 000	.....	2 000	89	10 000
June	1 171	2 000	.....	1 829	1 171	2 000	.....	3 829	1 171	2 000	.....	8 829
July	1 763	2 000	.....	66	1 763	2 000	.....	2 066	1 763	2 000	.....	7 066
August	66	509	.....	0	1 557	2 000	.....	509	1 557	2 000	.....	5 509
September	.....	222	.....	0	509	731	.....	0	1 778	2 000	.....	3 731
October	.....	393	.....	0	.....	393	.....	0	1 607	2 000	.....	2 124
November	.....	739	.....	0	.....	739	.....	0	1 261	2 000	.....	863
December	.....	1 332	.....	0	.....	1 332	.....	0	668	2 000	.....	195
1888. January	.....	2 000	.....	181	.....	2 000	.....	181	.....	2 000	.....	376
February	.....	2 000	.....	1 962	.....	2 000	.....	1 962	.....	2 000	.....	2 157
March	.....	2 000	3 670	3 000	.....	2 000	1 670	5 000	.....	2 000	.....	6 865
April	.....	2 000	3 304	3 000	.....	2 000	3 304	5 000	.....	2 000	169	10 000
May	.....	2 000	1 382	3 000	.....	2 000	1 382	5 000	.....	2 000	1 382	10 000
June	1 155	2 000	.....	1 845	1 155	2 000	.....	3 845	1 155	2 000	.....	8 845
July	1 757	2 000	.....	88	1 757	2 000	.....	2 088	1 757	2 000	.....	7 088
August	88	874	.....	0	1 214	2 000	.....	874	1 214	2 000	.....	5 874
September	.....	2 000	.....	316	.....	2 000	.....	1 190	.....	2 000	.....	6 190
October	.....	2 000	.....	2 458	.....	2 000	.....	3 332	.....	2 000	.....	8 332
November	.....	2 000	2 988	3 000	.....	2 000	1 862	5 000	.....	2 000	1 862	10 000
December	.....	2 000	4 305	3 000	.....	2 000	4 305	5 000	.....	2 000	4 305	10 000
1889. January	.....	2 000	3 765	3 000	.....	2 000	3 765	5 000	.....	2 000	3 765	10 000
February	.....	2 000	237	3 000	.....	2 000	237	5 000	.....	2 000	237	10 000
March	.....	2 000	774	3 000	.....	2 000	774	5 000	.....	2 000	774	10 000
April	.....	2 000	827	3 000	.....	2 000	827	5 000	.....	2 000	827	10 000
May	178	2 000	.....	2 822	178	2 000	.....	4 822	178	2 000	.....	9 822
June	690	2 000	.....	2 132	690	2 000	.....	4 132	690	2 000	.....	9 132
July	688	2 000	.....	1 444	688	2 000	.....	3 444	688	2 000	.....	8 444
August	.....	2 000	.....	2 410	.....	2 000	.....	4 410	.....	2 000	.....	9 410
September	348	2 000	.....	2 062	348	2 000	.....	4 062	348	2 000	.....	9 062
October	.....	2 000	.....	2 610	.....	2 000	.....	4 610	.....	2 000	.....	9 610
November	.....	2 000	1 502	3 000	.....	2 000	1 502	5 000	.....	2 000	1 502	10 000
December	.....	2 000	2 643	3 000	.....	2 000	2 643	5 000	.....	2 000	2 643	10 000

TABLE No. 4—(*Continued*).

Capacity of Reservoir.	3 000 000 000.				5 000 000 000.				10 000 000 000.			
	Drawn from reservoir.	Used.	Wasted.	In reservoir at end of month.	Drawn from reservoir.	Used.	Wasted.	In reservoir at end of month.	Drawn from reservoir.	Used.	Wasted.	In reservoir end of month.
1890. January	.....	2 000	598	3 000	.....	2 000	598	5 000	.....	2 000	598	10 000
February	.....	2 000	861	3 000	.....	2 000	861	5 000	.....	2 000	861	10 000
March	.....	2 000	5 548	3 000	.....	2 000	5 548	5 000	.....	2 000	5 548	10 000
April	.....	2 000	1 759	3 000	.....	2 000	1 759	5 000	.....	2 000	1 759	10 000
May	.....	2 000	831	3 000	.....	2 000	831	5 000	.....	2 000	831	10 000
June	862	2 000	.....	2 138	862	2 000	.....	4 138	862	2 000	.....	9 138
July	1 778	2 000	.....	360	1 778	2 000	.....	2 360	1 778	2 000	.....	7 360
August	.....	633	.....	0	1 727	2 000	.....	633	1 727	2 000	.....	5 633
September	.....	917	.....	0	633	1 550	.....	0	1 083	2 000	.....	4 550
October	.....	2 000	.....	2 708	.....	2 000	.....	2 708	.....	2 000	.....	7 258
November	.....	2 000	144	3 000	.....	2 000	.....	3 144	.....	2 000	.....	7 694
December	.....	2 000	63	3 000	.....	2 000	.....	3 207	.....	2 000	.....	7 757
1891. January	.....	2 000	4 253	3 000	.....	2 000	2 460	5 000	.....	2 000	2 010	10 000
February	.....	2 000	4 523	3 000	.....	2 000	4 523	5 000	.....	2 000	4 523	10 000
March	.....	2 000	7 227	3 000	.....	2 000	7 227	5 000	.....	2 000	7 227	10 000
April	.....	2 000	2 806	3 000	.....	2 000	2 806	5 000	.....	2 000	2 806	10 000
May	793	2 000	.....	2 207	793	2 000	.....	4 207	793	2 000	.....	9 207
June	1 171	2 000	.....	1 036	1 171	2 000	.....	3 096	1 171	2 000	.....	8 036
July	1 036	1 347	.....	0	1 691	2 000	.....	1 405	1 691	2 000	.....	6 347
August	.....	337	.....	0	1 405	1 742	.....	0	1 663	2 000	.....	4 684
September	.....	406	.....	0	.....	406	.....	0	1 594	2 000	.....	3 090
October	.....	435	.....	0	.....	435	.....	0	1 565	2 000	.....	1 525
November	.....	611	.....	0	.....	611	.....	0	1 389	2 000	.....	136
December	.....	1 128	.....	0	.....	1 128	.....	0	136	2 000	.....	0
1892. January	.....	2 000	.....	1 874	.....	2 000	.....	1 874	.....	2 000	.....	1 874
February	207	2 000	.....	1 667	207	2 000	.....	1 667	207	2 000	.....	1 667
March	.....	2 000	718	3 000	.....	2 000	.....	3 718	.....	2 000	.....	3 718
April	253	2 000	.....	2 747	253	2 000	.....	3 465	253	2 000	.....	3 465
May	.....	2 000	355	3 000	.....	2 000	.....	4 073	.....	2 000	.....	4 073
June	1 142	2 000	.....	1 858	1 142	2 000	.....	2 931	1 142	2 000	.....	2 931
July	1 557	2 000	.....	301	1 557	2 000	.....	1 374	1 557	2 000	.....	1 374
August	301	882	.....	0	1 374	1 955	.....	0	1 374	1 955	.....	0
September	.....	460	.....	0	.....	460	.....	0	.....	460	.....	0
October	.....	260	.....	0	.....	260	.....	0	.....	260	.....	0
November	.....	1 398	.....	0	.....	1 398	.....	0	.....	1 398	.....	0
December	.....	1 050	.....	0	.....	1 050	.....	0	.....	1 050	.....	0

TABLE No. 5.

STEAM-POWER REQUIRED TO MAKE UP A UNIFORM TOTAL OF 1 000 H. P. 24 HOURS A DAY, IN A MILL COMMANDING 500 SQ. MILES OF NEW ENGLAND DRAINAGE AREA, WITH RESERVOIRS TO THE EXTENT OF 3 000 000 000 CU. FT. HEAD, 15 FT. POWER EXPRESSED IN HORSE-POWER 24 HOURS A DAY.

	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1863	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1864	.....	.....	.....	.....	.....	.....	36	623	716	170	274	228
1865	.....	.....	.....	.....	.....	.....	35	727	739	594	420	344
1866	576	.....	.....	.....	.....	.....	303	628	222	460	425	94
1867	362	.....	.....	.....	.....	.....	.....	.....	381	408	362	350
1868	292	350	.....	.....	.....	.....	.....	.....	.....	4	.....	182
1869	.....	.....	.....	.....	.....	.....	.....	163	362	.....	.....	.....
1870	.....	.....	.....	.....	.....	.....	.....	428	501	356	489	553
1871	402	.....	.....	.....	.....	.....	373	507	774	600	245	296
1872	332	460	181	.....	.....	.....	627	234	13	19	.....	136
1873	.....	.....	.....	.....	.....	.....	.....	66	547	.....	.....	.....
1874	.....	.....	.....	.....	.....	.....	.....	.....	107	698	664	704
1875	894	.....	.....	.....	.....	.....	.....	.....	678	331	.....	90
1876	334	.....	.....	.....	.....	.....	89	580	816	758	.....	440
1877	319	112	.....	.....	.....	.....	.....	317	940	346	.....	.....
1878	.....	.....	.....	.....	.....	.....	.....	368	839	465	.....	.....
1879	.....	.....	.....	.....	.....	.....	.....	514	859	927	794	521
1880	.....	.....	.....	.....	.....	.....	620	877	920	895	795	819
1881	571	.....	.....	.....	.....	.....	.....	61	803	808	604	197
1882	.....	.....	.....	.....	.....	.....	.....	823	693	691	790	675
1883	654	34	.....	.....	.....	.....	587	187	909	808	795	800
1884	.....	.....	.....	.....	.....	.....	.....	585	956	914	825	42
1885	.....	.....	.....	.....	.....	.....	8	751	879	652	.....	.....
1886	.....	.....	.....	.....	.....	.....	432	903	882	849	326	.....
1887	.....	.....	.....	.....	.....	.....	.....	746	889	804	631	334
1888	.....	.....	.....	.....	.....	.....	.....	563	.....	.....	.....	.....
1889	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1890	.....	.....	.....	.....	.....	.....	.....	684	542	.....	.....	.....
1891	.....	.....	.....	.....	.....	.....	327	832	797	783	695	436
1892	.....	.....	.....	.....	.....	.....	.....	558	770	870	301	475

TABLE No. 6.

STEAM-POWER REQUIRED TO MAKE UP A UNIFORM TOTAL OF 1 000 H. P. 24 HOURS A DAY IN A MILL COMMANDING 500 SQ. MILES OF NEW ENGLAND DRAINAGE AREA, WITH RESERVOIRS TO THE EXTENT OF 5 000 000 000 CU. FT. HEAD, 15 FT. POWER EXPRESSED IN HORSE-POWER, 24 HOURS A DAY.

	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1863	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1864	.....	.....	.....	.....	.....	.....	.....	.....	375	170	274	228
1865	.....	.....	.....	.....	.....	.....	.....	.....	502	594	420	344
1866	576	.....	.....	.....	.....	.....	303	629	222	460	425	94
1867	362	.....	.....	.....	.....	.....	.....	.....	.....	.....	150	350
1868	292	350	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1869	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1870	.....	.....	.....	.....	.....	.....	.....	.....	.....	284	489	553
1871	402	.....	.....	.....	.....	.....	373	507	774	600	245	296
1872	332	460	181	.....	.....	.....	627	234	13	19	.....	136
1873	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1874	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	469	704
1875	894	.....	.....	.....	.....	.....	.....	.....	.....	9	.....	90
1876	334	.....	.....	.....	.....	.....	.....	.....	484	758	.....	440
1877	319	112	.....	.....	.....	.....	.....	.....	258	346	.....	.....
1878	.....	.....	.....	.....	.....	.....	.....	.....	207	465	.....	.....
1879	.....	.....	.....	.....	.....	.....	.....	.....	373	927	794	521
1880	.....	.....	.....	.....	.....	.....	620	877	920	895	795	819
1881	571	.....	.....	.....	.....	.....	.....	.....	.....	672	604	197
1882	.....	.....	.....	.....	.....	.....	.....	.....	516	691	790	675
1883	654	34	.....	.....	.....	.....	587	187	909	808	795	800
1884	.....	.....	.....	.....	.....	.....	.....	.....	541	914	825	42
1885	.....	.....	.....	.....	.....	.....	.....	.....	760	652	.....	.....
1886	.....	.....	.....	.....	.....	.....	.....	334	882	849	326	.....
1887	.....	.....	.....	.....	.....	.....	.....	.....	635	804	631	334
1888	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1889	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1890	.....	.....	.....	.....	.....	.....	.....	.....	225	.....	.....	.....
1891	.....	.....	.....	.....	.....	.....	.....	129	797	783	695	436
1892	.....	.....	.....	.....	.....	.....	.....	23	770	870	301	475

TABLE No. 7.

STEAM-POWER REQUIRED TO MAKE A UNIFORM TOTAL OF 1 000 H. P. 24 HOURS A DAY IN A MILL COMMANDING 500 SQ. MILES OF NEW ENGLAND DRAINAGE AREA, WITH RESERVOIRS TO THE EXTENT OF 10 000 000 000 CU. FT. HEAD, 15 FT. POWER EXPRESSED IN HORSE-POWER, 24 HOURS A DAY.

	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1863	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1864	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1865	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1866	.....	.....	.....	.....	.....	.....	237	629	222	460	425	94
1867	362	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1868	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1869	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1870	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1871	.....	.....	.....	.....	.....	.....	.....	107	774	600	245	296
1872	332	460	181	.....	.....	.....	627	234	13	19	.....	136
1873	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1874	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1875	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1876	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1877	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1878	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1879	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	115
1880	.....	.....	.....	.....	.....	.....	620	877	920	895	795	819
1881	571	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1882	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	303	675
1883	654	34	.....	.....	.....	.....	587	187	909	808	795	800
1884	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1885	.....	.....	.....	.....	.....	.....	.....	.....	581	652	.....	.....
1886	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1887	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1888	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1889	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1890	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1891	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1892	.....	.....	.....	.....	.....	.....	.....	23	770	870	301	475

TABLE No. 8.

COST OF STEAM-POWER TO MAINTAIN 1 000 H. P. 24 HOURS A DAY IN A MILL COMMANDING 500 SQ. MILES OF NEW ENGLAND DRAINAGE AREA, WITH RESERVOIRS OF DIFFERENT SIZES. HEAD, 15 FT.

	No reservoir.	3 000 000 000.	5 000 000 000.	10 000 000 000.
1863	$12 183.60	0.00	.....	.....
1864	28 227.30	$16 060.50	$8 084.40	.....
1865	33 777.00	22 278.60	14 278.80	.....
1866	26 601.00	21 308.40	21 308.40	$16 155.90
1867	27 531.90	14 434.50	6 682.20	2 932.20
1868	19 847.70	6 337.20	4 885.20	.....
1869	17 280.30	4 095.00	0.00	.....
1870	29 709.00	18 132.30	10 196.10	.....
1871	32 108.10	24 814.50	24 814.50	15 641.40
1872	22 907.70	15 470.40	15 470.40	15 470.40
1873	16 873.80	4 781.40	.....	.....
1874	28 468.20	16 760.40	8 868.00	.....
1875	29 640.00	15 545.40	7 745.40	.....
1876	35 713.80	23 547 90	15 592.80	.....
1877	29 372.40	15 777.00	8 094.30	.....
1878	24 633.90	13 039.80	5 319.00	.....
1879	41 750.40	27 998.70	20 198.70	897.00
1880	49 798.50	38 184.30	38 184.30	38 184.30
1881	35 301.90	23 580.30	15 762.00	4 453.80
1882	40 862.70	28 449.00	20 402.20	7 335.00
1883	44 673.90	36 774.00	36 774.00	36 774.00
1884	37 184.40	25 651.50	17 976.00	.....
1885	29 765.40	18 057.60	11 209.20	9 813.00
1886	38 216.70	26 516.70	18 708.90	.....
1887	38 038.80	26 585.70	18 561.90	.....
1888	16 017.60	4 560.30	.....	.....
1889	7 296.60	.....	.....	.....
1890	20 970.90	9 460.20	1 687.50	.....
1891	41 838.60	30 004.50	21 969.90	.....
1892	36 651.30	23 274.30	18 934.80	18 940.80
Totals	$893 213.40	$551 420 40	$391 708.90	$166 597.80
Averages	29 773.78	18 380.68	13 056.96	5 553.26

Subtracting the average of the third, fourth and fifth columns, respectively, from that of the second, we find:

The annual saving consequent upon a reservoir capacity of 3 000 000 000..... $11 393 10

The annual saving consequent upon a reservoir capacity of 5 000 000 000..... 16 716 82

The annual saving consequent upon a reservoir capacity of 10 000 000 000..... 24 220 52

These figures show what we knew perfectly well before, viz., that the benefit of reservoirs to one single establishment, or one mill privilege, is hardly ever sufficient to warrant the expense of their con-

struction. The total head to be served must usually be as much as 100 ft., to bring such projects within the range of feasibility. Exceptions occur when the level of natural lakes can be raised at slight expense, but such opportunities in New England are now nearly all appropriated.

Suppose six such establishments lying on the same stream with an aggregate fall of 90 ft. In this case the aggregate saving would be :

For a reservoir of	3 000 000 000.....	$68 358 60 per annum.
" "	5 000 000 000.....	100 300 92 "
" "	10 000 000 000.....	145 323 12 "

and the cost at which such reservoirs would be a 10% investment would be—

For	3 000 000 000.....	$683 586 or $228 per 1 000 000
"	5 000 000 000.....	1 003 009 " 201 " "
"	10 000 000 000.....	1 453 231 " 145 " "

At the highest of these figures, opportunities for storage can usually be found in most New England river valleys. At the lowest their occurrence cannot usually be counted on.

Let us suppose a series of establishments on the same stream, circumstanced as above with reference to power, having an aggregate fall of 150 ft., which is a case by no means unusual. In this case the cost at which reservoirs would be a 10% investment, would be $380 per 1 000 000 for 3 000 000 000; $334 per 1 000 000 for 5 000 000 000; and $242 per 1 000 000 for 10 000 000 000. Of course, any capacity under 3 000 000 000 would be obtained upon equally or more advantageous terms. It would be rare, indeed, if opportunities for storage could not be obtained at these figures.

These tables throw light upon other controverted questions upon the subject of power. How often do we hear it said that water-power has had its day. It is going out of use. It is being superseded by steam, etc.

The total volume of water discharged by the 500 sq. miles of drainage ground in the assumed period of 30 years would be 769 200 000 000 cu. ft. The quantity used for power in connection with steam is 482 600 000 000. Consider, now, how much could have been used if no steam had been employed. A mill drawing 500 000 000 cu. ft. per month, which

is something like 200 cu. ft. per second, exclusive of wastage, would have been short of water 63 times during the 30-year period, so that 500 000 000 a month is the most that could have been profitably used by such a mill. The entire volume used by such a mill would have been 168 166 000 000 cu. ft. against 482 600 000 000 available when used in connection with steam. We are entitled to say then, that of the total flow from a given drainage ground, or given stream, approximately three times as much can be made available for power by the aid of steam as can be used to any rational purpose without it. So far from water-power being superseded or rivaled by steam, it is only in connection with steam that it attains its most complete development.

Another point may be adverted to in this connection. It is sometimes asserted that it is cheaper to use steam alone than to run steam in connection with water-power.

Compare the cost of power in a mill running as assumed in these tables with that in a mill using the same power obtained from steam alone. We will roughly estimate the cost of water-power plant at $80 per horse-power, say, $80 000 for 1 000 H. P.

We will admit that steam-power in an engine used to make up deficiencies of water-power costs 50% more than in an engine running constantly at full load; that is, 20% more than assumed in Table No. 8.

For the mill using water and steam the account would stand thus:

Cost of steam 20% more than in Table No. 8.....	$35 728 54
Interest on cost of water-power plant at 5%.....	4 000 00
Sinking fund for entire renewal of water-power plant in 30 years at 5%.....	1 130 60
Maintenance and care of water-power.....	2 500 00
Total.....	$43 359 14

For the mill using steam alone:

1 000 H. P., 308 days, 24 hours per day, at 1 cent per hour. $739 20

This sum might reasonably be abated by the advantage which this mill would have in obtaining heat by waste steam during the winter, an advantage not possessed by the other, which has no use for steam-power during the winter. But making due allowance for this advantage, the cost is in favor of the mill using water-power by 50 per cent.

These tables also throw some light on the question of the absolute cash value of water-power, a subject on which wildly diverging opinions

are often expressed. Thus, if we can correctly determine the cost of power for an establishment such as is contemplated, when run wholly by steam, and again when run in connection with the water-power, the difference, as it appears to the writer, may be accepted as the accurate value of the water-power. If, for instance, we could assign $6 000 per annum as the value of the advantage possessed by the first-named establishment in respect to heating, the case would stand thus:

Cost per annum for steam-power alone	$67 920 00
" " steam and water.....	43 359 14
Value of water per annum.....	$24 560 86

This sum is what the mill could afford to pay annually for the water used for power, and still stand upon an equal footing with an establishment run wholly by steam at the same place.

The foregoing remarks do not apply to the case of a mill engaged in bleaching, dyeing and similar operations requiring great amounts of heat.

Pondage.—Hardly less important than storage, or the retention of flood water for use during times of scarcity, is pondage or the retention of the flow of a stream during non-working hours, for use during working hours.

To have supposed the water used during the working hours of the secular day, in the preceding computations, would have introduced too large an element of hypothesis and made the matter too complex. This embarrassment we have avoided by assuming the mill to run throughout the 24 hours. Flour mills, lumber mills and paper mills usually run in this manner, and require no pondage. Textile mills more commonly run in the daylight and during the working hours established by law or custom.

We have taken the maximum limit of the use of water at 800 cu. ft. per second, which is very nearly the average flow of the stream for the entire period considered. This is as large a use as is ordinarily made by an establishment running 24 hours a day, though, no doubt, a still larger use might in some cases be made with advantage. An establishment running 10 hours a day, and designed to make full use of this quantity of water, must be organized upon an entirely different basis. All its buildings, machinery, boilers, engines, water-wheels, raceways, etc., would require to be on a scale of magnitude about 2½ times as great, and it would require pondage to hold 800

cu. ft. per second during the time that the wheels are not running, viz., about 46 800 seconds each day; that is to say, about 37 500 000 cu. ft. of pondage. The maximum limit of the use of water would be $800 \times 24 \div 10 = 1\,920$ cu. ft. per second.

In the actual running of mills it is very seldom practicable to use the water to this extent. The amount of pondage pertaining to a mill privilege depends usually upon the height of its dam and the declivity of the bed of the stream above the dam, and has no relation to the requirements for power. Practically, the mill makes use of what pondage it has, and, beyond this, allows the night flow to run to waste. The flow of Sundays and holidays would run to waste even with the pondage of 37 500 000, as given above. To avoid this waste, we should ordinarily have to hold the flow for about 40 hours, requiring $800 \times 40 \times 3\,600 = 115\,200\,000$ cu. ft. of pondage.

To exhibit the value of pondage by the same rigorously exact methods as have been adopted with reference to storage, Tables Nos. 9 and 10 have been computed. These tables assume an establishment with the same drainage area and the same fall as in the former case, running 10 hours a day and stopping one hour at noon, its maximum use of water being 1 000 cu. ft. per second. In Table No. 9 the first column is the natural flow of the stream in cubic feet per second, for each 25 ft. from 50 to 1 000. The second column gives the quantity of water which the mill is able to use with any given flow of the stream and 10 000 000 cu. ft. of pondage. Thus, with 50 cu. ft. per second, the entire flow of 168 hours can be saved and drawn in the 60 working hours, giving a draft of 140 cu. ft. per second. The same with a flow of 75 cu. ft. per second. With a flow of 100 cu. ft. per second there is a little wastage of the Sunday flow. Above 214 cu. ft. per second the Sunday flow is wholly wasted. Above this stage the computation is as follows, say for a flow of 225 cu. ft. per second:

In pond at starting of mill.....			10 000 000 cu. ft.
One hour's flow held at noon = 225 × 3 600...			810 000 "
Pondage drawn in 10 hours or 36 000 seconds..... =	300 cu. ft.	per second	10 810 000 "
Add natural flow.....	225 "	"	
Total draft of mill.	525 "	"	

The third column gives the gain from pondage in cubic feet per second; the fourth, the same in horse-power; the fifth, the value of

equivalent steam-power per diem, taking steam-power, as in the former case, at 12½ cents per horse-power per day. When the draft reaches 1 000 cu. ft. per second, the gain from pondage begins to diminish; and when the natural flow of the stream reaches 1 000 cu. ft. per second, there is no further gain from pondage. The sixth, seventh, eighth and ninth columns are the same as the second, third, fourth and fifth, except that the former refer to a pondage of 20 000 000, the latter to one of 10 000 000.

TABLE No. 9.

VALUE OF PONDAGE TO A MILL COMMANDING 500 SQ. MILES OF NEW ENGLAND DRAINAGE AREA, RUNNING 10 HOURS A DAY AND CAPABLE OF USING 1 000 CU. FT. OF WATER PER SECOND. HEAD, 15 FT.

Flow of stream in cubic feet per second.	10 000 000 cu. ft. of pondage.				20 000 000 cu. ft. of pondage.			
	Draft of mill in cubic feet per second.	Gain from pondage.		Cost per diem of steam-power equivalent to gain from pondage.	Draft of mill in cubic feet per second.	Gain from pondage.		Cost per diem of steam-power equivalent to gain from pondage.
		Cubic feet per second.	Horse-power.			Cubic feet per second.	Horse-power.	
50	140	90	112	$14.00	140	90	112	$14.00
75	210	135	169	21.12	210	135	169	21 12
100	265	165	206	25.75	280	180	225	28.12
125	319	194	242	30.25	350	225	281	35.12
150	372	222	277	34.62	420	270	337	42.12
175	428	253	316	39.50	475	300	375	46.87
200	483	283	354	44.25	530	330	412	51.50
225	525	300	375	46.87	584	359	449	56.12
250	553	303	379	47.37	639	389	486	60.75
275	580	305	380	47.50	693	418	522	65.25
300	608	308	385	48.12	748	448	560	70.00
325	635	310	387	48.37	802	477	595	74.50
350	663	313	391	48.87	857	507	634	79.25
375	690	315	394	49.25	911	536	670	83.75
400	718	318	397	49.62	960	560	700	87.50
425	745	320	400	50.00	995	570	712	89.00
450	773	323	404	50.50	1 000	550	687	85.87
475	800	325	406	50.75	1 000	525	656	82.00
500	828	328	410	51.25	1 000	500	625	78.12
525	856	331	414	51.75	1 000	475	594	74.25
550	883	333	416	52.00	1 000	450	562	70.25
575	911	336	420	52.50	1 000	425	531	66.37
600	938	338	422	52.75	1 000	400	500	62.50
625	965	340	425	53.12	1 000	375	469	58.62
650	993	343	429	53.62	1 000	350	437	54.62
675	1 000	325	406	50.75	1 000	325	406	50.75
700	1 000	300	375	46.87	1 000	300	375	46.87
725	1 000	275	344	43.00	1 000	275	344	43.00
750	1 000	250	312	39.00	1 000	250	312	39.00
775	1 000	225	281	35.12	1 000	225	281	35.12
800	1 000	200	250	31.25	1 000	200	250	31.25
825	1 000	175	219	27.37	1 000	175	219	27.37
850	1 000	150	187	23.37	1 000	150	187	23.37
875	1 000	125	156	19.50	1 000	125	156	19.50
900	1 000	100	125	15.62	1 000	100	125	15.62
925	1 000	75	94	11.75	1 000	75	94	11.75
950	1 000	50	62	7.75	1 000	50	62	7.75
975	1 000	25	31	3.87	1 000	25	31	3.87
1 000	1 000	0	0	0	1 000	0	0	0

Table No. 10 gives the aggregate value of pondage for each year of the series. It is computed from Table No. 9 and Table No. 1, with the aid of the calender of the several years. Thus, for the year 1865, with a pondage of 10 000 000:

January.—Average flow, 932. Value of pondage per diem, $10 63. Number of working days, 26							26 x $10 63	=	$276 38
February.	Flow,	835.	Days,	23.	Value pondage,	$25 77	23 x 25 77	=	592 71
June.	"	149.	"	26.	"	"	34 45	26 x 34 45 =	895 70
July.	"	199.	"	25.	"	"	44 06	25 x 44 06 =	1 101 50
August.	"	204.	"	27.	"	"	44 67	27 x 44 67 =	1 206 09
September.	"	201.	"	26.	"	"	44 35	26 x 44 35 =	1 153 10
October.	"	303.	"	26.	"	"	48 15	26 x 48 15 =	1 251 90
November.	"	448.	"	25.	"	"	50 46	25 x 50 46 =	1 261 50
December.	"	490.	"	25.	"	"	51 05	25 x 51 05 =	1 276 25

Value of pondage, 10 000 000 cu. ft. for 1865 ..... $9 015 13

TABLE No. 10.

VALUE OF PONDAGE FOR A SERIES OF YEARS TO A MILL COMMANDING 500 SQ. MILES OF NEW ENGLAND DRAINAGE AREA, AND RUNNING 10 HOURS A DAY. HEAD, 15 FT.

Year.	Saving in Steam Power with—		Year.	Saving in Steam Power with—	
	10 000 000 cu. ft. of pondage.	20 000 000 cu. ft. of pondage.		10 000 000 cu. ft. of pondage.	20 000 000 cu. ft. of pondage.
1863.....	$7 382.39	$9 806.91	1878.....	$5 318.63	$8 329.41
1864.....	10 989.73	12 965.00	1879.....	8 421.89	11 587.40
1865.....	9 015.13	12 008.18	1880.....	7 369.06	8 438.36
1866.....	13 778.64	19 123.17	1881.....	7 328.73	8 878.23
1867.....	9 037.74	13 409.27	1882.....	6 801.70	10 117.82
1868.....	10 013.91	13 788.23	1883.....	9 577.74	11 050.22
1869.....	7 967.86	10 799.78	1884.....	7 820.73	9 058.85
1870.....	9 807.46	14 589.50	1885.....	5 481.03	6 837.64
1871.....	11 355.77	13 882.46	1886.....	6 865.17	8 286.00
1872.....	12 204.44	15 942.47	1887.....	7 585.85	10 127.32
1873.....	6 982.52	8 595.21	1888.....	4 362.39	5 643.21
1874.....	8 744.71	11 863.72	1889.....	5 769.89	8 091.06
1875.....	8 381.44	11 748 32	1890.....	5 031.00	6 888.21
1876.....	8 607.26	11 576 60	1891.....	8 501.88	12 117.79
1877.....	6 922.36	9 498.21	1892.....	9 879.13	12 500.84
Average.....				$8 240.31	$10 918.31

The recently established holidays, Labor Day and Decoration Day, are not counted. Table No. 10 being given, not for reference, but for illustration, the computations have not been checked. They are substantially correct, but not free from trifling errors. The average result for the entire period of 30 years is $8 240 31 for a pondage of 10 000 000,

and $10 918 31 for a pondage of 20 000 000. These sums represent the average annual benefit of the respective amounts of pondage to an establishment running under the conditions supposed, as compared with one running under the same conditions without pondage. These results would appear larger if we should assume a larger maximum use of water; that is, if we assume the establishment capable of using 1 200 or 1 500 cu. ft. of water per second, instead of 1 000.

In the case of a series of mills running 10 hours a day, and supplied by storage reservoirs, it often happens that the daily discharge from the reservoirs does not reach the mills within the working hours, and more or less pondage is necessary in order to make the discharge of the reservoirs available and avoid waste. No greater amount of pondage, however, is necessary for this purpose than would be required to make an equally complete use of the natural flow of the same stream; generally less.

In the case of a series of mills occupying different falls on the same stream, the pond of each mill reaching to the dam of the next above, it is sometimes advantageous to provide a large pond at the head of the line. Each mill, then, on starting, draws from its own pondage only till it receives water from the next above, and the single pond serves the whole series. This is the case at Gardiner, Me., where there is a succession of dams supplied by the Cobossee Contee River. This stream, draining about 215 sq. miles, has some 2 500 000 000 or 3 000 000 000 cu. ft. of storage capacity, and has a pond at the head of the series of dams capable of holding the discharge of the reservoirs while the mills are stopped. This is usually only on Sundays and holidays, the mills being mostly paper mills.

The most fortunate condition is when the same basin serves both for storage and pondage. This case occurs at Rockville, in Connecticut. Here, Lake Shenipsit, near the head of the Hockanum River, has a drainage area of some 15 sq. miles, and is controlled by a dam to the extent of some 24 ft., holding practically the entire flow of the drainage ground. Below the dam is a series of mill privileges, with an aggregate fall of more than 250 ft. The declivity is so great that the pondage appurtenant to each dam is very small. These are mostly textile mills, and run but 10 hours a day. The reservoir gates are opened only during working hours. As soon as any mill commences to draw from its pond the mill above commences to discharge into the

same, and very little water runs to waste. Very rarely does so small an extent of drainage ground furnish power for so large an amount of machinery.

The construction of a system of storage reservoirs, or any similar enterprise, in the common interest of a number of mill owners, presupposes a concert of action and a spirit of mutual concession and accommodation among the parties very rarely met with. Mutual jealousies and bickerings over trivial points usually prove fatal obstacles to such projects. For this reason it is customary and advisable for the parties in interest before commencing such an undertaking to appoint a board of arbitration empowered to apportion the expense and to adjust all questions requiring mutual agreement of the parties.

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RECLAMATION OF THE POTOMAC FLATS AT WASHINGTON, D. C.*

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READ DECEMBER 20TH, 1893.

The Potomac River from Little Falls to its mouth is a tidal stream, the tidal range being 3 ft. at Washington, and about 1½ ft. at its mouth. Above the Falls the tides have no effect whatever. The lower part of the river is broad, but there is a good channel all the way to Washington, rather shoal in a few places, and bordered on the sides with large areas of flats or marshes which support a rank growth of eel grass.

Ever since we have had definite knowledge of the river, such as is derivable from maps, etc., there have been no less than two channels in the harbor of Washington, and a part of the time three. The most southerly one of these, called the Virginia Channel, and naturally the widest and deepest, followed along the Virginia shore, and passed between it and Mason's Island (now called Analostan Island). When the upper end of this channel was closed by the construction of a dam or causeway, between the island and the Virginia shore, in 1806, it was

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forced over to the Georgetown side and became sometimes known as the Georgetown Channel. The causeway was built with a view to deepening the channel at the cross-over below Analostan Island. It was already deep along the Georgetown front. The island became, in fact, a training dike, but it was not long enough. The shoal place remained shoal, as might have been anticipated. At the same time a large area of flats was created in the dead water below the island.

A second channel, sometimes called the "swash," branched off from the Washington Channel, opposite the foot of Sixth Street, pursued a southwest course, passed through the middle of what is now the causeway of Long Bridge, and united with the Virginia Channel a short distance below Easby's Point. In the early days this seems to have been a fairly good channel, having a navigable depth of 6 ft. at mean low tide. This channel is shown by the maps to have filled up, to a great extent, by 1834, the date of the Kearney survey, and the subsequent construction of Long Bridge causeway caused its total obliteration. There is a popular notion that the construction of this causeway produced the filling up of this channel. This is an error. The causeway was not built until 1836, and at that date it had already filled up. That it accelerated the process afterward is doubtless true; but it is a perversion of the terms, cause and effect, to attribute the original filling-up process to the causeway.

The third channel, called the Washington Channel, branched off from the main channel opposite the mouth of the Eastern Branch, and followed along the Washington shore to Easby's Point where it again united with the Virginia Channel. There is a popular notion that this channel was deep at its upper end, so that vessels of good size could follow it all the way to Georgetown. But it must have been a very long time ago when such was the case. The survey of 1792 (Plate III) shows that there was only a navigable depth of 3 ft. at mean tide, which corresponds to $1\frac{1}{2}$ ft. at mean low tide. General Braddock is said to have landed his army in the cove below Easby's Point, but even this might be true and the depth of water not great. Surveys made subsequent to 1792 shows that the little channel continued to fill up, so that by 1834 it had entirely filled up—the remains of it existed in the shape of a narrow drain between the shore and the flats outside of it. By 1862 the upper part of the channel had disappeared entirely and was lost in a broad expanse of flats. There only remained the two channels, the

Virginia, or Georgetown, Channel on the south side, and the Washington Channel, which practically terminated at Long Bridge.

The same causes that produced the shoaling of the channels produced the formation known as the Potomac Flats. They are the direct result of the physical conditions at the time existing. At Easby's Point, which marks their upper limit, the river is only about 900 ft. wide, estimating to Analostan Island, which was united to the Virginia shore by the dam already referred to, while immediately below it was from 5 000 to 6 000 ft. This sudden expansion in width naturally caused a deposit of silt in this part of the river in times of freshets, filling the channel to some extent, but filling still more in the eddies and dead water behind Easby's Point. The drainage area of the Potomac is about 20 000 sq. miles; consequently, freshets attain huge proportions. The river rises at such times to a height of 40 to 45 ft. at the Falls and becomes a huge torrent, the discharge having been roughly estimated at about 380 000 cu. ft. per second. An immense amount of silt is brought down with it, which finds a resting place during the progress of the freshet in the eddies behind projecting points, and, as the freshet subsides, quantities are deposited in the channels themselves.

In this way the channels have been filling up, requiring frequent dredging to maintain the requisite depth for commerce, and the Potomac flats have been growing year by year until they had become a nuisance to the city. Of late years this nuisance had been aggravated by the large amount of sewage that was discharged on them. The city had been growing, and the question of sewage disposal had not engaged the attention of the community or Congress to the extent that it should. A grave error in sewage disposal was committed when the old canal that ran along B Street was converted into a sewer, with its discharge on the flats at the foot of Seventeenth Street. The greater part of the flats being covered at about half tide, the sewage spread out on them, and, when the tide went out, left it in putrid masses, exposed to the direct rays of the sun. The vicinity of the outlet of this sewer became a pestilential swamp, the stench from which was at times almost intolerable. The Presidential mansion, being distant only about half a mile, got the full benefit of the condition of affairs when the wind was from the south.

To correct this growing evil was a problem that had engaged the

attention of the public for some time, and various plans had been suggested. A change in the disposal of the sewage would only ameliorate the conditions. It would not cure them. The flats would still be there, and the nuisance would be perpetuated, though in a less objectionable form. The question was: Should the flats be reclaimed by filling on top of them so as to raise the surface above the level of overflow, or should they be dug out, thereby creating a large area of deep water in front of the city, or should they be diked in and pumped out? All these plans had their advocates, and all were more or less discussed in the public press. To undertake to discuss the merits and demerits of the various plans would not be practicable within the limits of this paper. It will be sufficient to note the salient features of those that were most seriously considered, and a little more in detail the one that was adopted.

Mr. Alfred L. Rives, a civil engineer, was one of the first to treat the subject from a professional standpoint. In his report, transmitted to Congress by the Secretary of the Interior in 1857, he submitted plans and estimates for an iron suspension and stone arch bridge across the Potomac, on the site of the existing Long Bridge. He states that the plans for a permanent bridge at Washington are so intimately connected with the project for the improvement of the navigation of the river that one cannot be properly matured without due consideration of the other. He might have added that the improvement of navigation was also in the same way intimately connected with the reclamation of the flats. His plan of improvement was to open the old swash channel, fill out to the edge of it on the Washington side, turn the waters of the Virginia Channel into the new one by means of a breakwater built out from the lower end of Analostan Island, and reconstruct Long Bridge. This plan would reclaim 166 acres on the Washington side, but would have brought about just the conditions for forming a much larger area for flats on the opposite side of the river. A peculiar feature was that very little dredging was to be done in the formation of the new channel; most of it was to be formed by the supposed scour that would take place. The flats were to be filled by material taken from the grading of streets, etc.

Another plan, wholly dissimilar from that of Mr. Rives, was proposed by the Board of Survey of 1872. This was to advance the city front along the whole line out to the Virginia Channel; to construct

a bulkhead along the entire front, with docks in number and size sufficient to accommodate commerce, and to fill in the area between the new and the old fronts, chiefly with dredgings taken from the river, which was to be deepened to 23 ft. at mean low tide. This plan would reclaim 1 050 acres, all of which was to be laid out in streets and lots, by extending the existing streets over the area to be reclaimed. There were many other minor details connected with this plan, which it is unnecessary to refer to. It was a work of great magnitude as planned.

In 1879, Major Twining, at the time Engineer Commissioner of the District of Columbia, submitted a plan for improving navigation and filling the flats, which was a modification of the plan of the Board of Survey. His plan advanced the city front, but not as far. The Washington Channel was to be kept open as far as Long Bridge, which was a practical extension of the Board's winter harbor. He introduced an entirely new feature which had not up to that time been considered, viz., the flushing ponds or lakes. Under his plan the Washington Channel became a tidal arm of the river, closed at its upper end from all connection with the river. To overcome the objections urged, that this comparatively small body of water would become stagnant and polluted, he proposed to occupy about 114 acres of the space between Long Bridge and the sewer canal with lakes, which were to be arranged with inlet and outlet gates, working automatically with the tides, taking the water in from the Virginia Channel on the flood, and discharging it into the head of the Washington Channel on the ebb. The entire space between the bridge and sewer canal was to be converted into a park, the lakes forming an ornamental feature; the other spaces, below the bridge, and above the sewer canal, were to be laid out in streets and lots, the latter were to be sold. He proposed to fill the entire area to a height of 4 ft. above the freshet line of 1877. The plan reclaimed about 528 acres.

In January, 1882, Mr. S. T. Abert, civil engineer, submitted a plan, which was the same in its general features as that of Major Twining, except that he proposed to fill the flats only to the level of 6 ft. above low tide, and protect it from overflow by a surrounding embankment.

In February, 1882, a board of engineers, consisting of Lieutenant-Colonels Q. A. Gillmore, William P. Craighill, and C. B. Comstock, Corps of Engineers, U. S. A., submitted a plan combining sub-

stantially and in its essential features the harbor and shore lines of Mr. Abert's plan, with the low-grade filling and surrounding embankment of that plan, below Long Bridge, with Twining's high-grade filling and sluicing ponds between Long Bridge and Easby's Point. The Board regarded the rebuilding of Long Bridge with wider spans on piers, offering less obstruction to the flow of water, as essential.

The plan of the Board of Engineers was the one adopted by Congress, and has been nearly carried out. The low-grade filling with the surrounding embankment below Long Bridge was subsequently modified to a fill 3 ft above the freshet line of 1877, along the axis of this area, which was tongue-shaped in plan, sloping off to about 6 ft. above low tide at the margin on either side. For the flushing ponds, of which there were four, all communicating with each other, as proposed by Twining, a single lake or reservoir was substituted. The total area of flats reclaimed is about 625 acres exclusive of the reservoir, requiring about 12 329 000 cu. yds. of material.

The act making the appropriation provided for improving the navigation, the raising of the flats, and the establishment of the harbor lines. The law itself, therefore, contemplated that the material, or at least most of it, should be taken from the bed of the river; but whether contemplated or not, it was the only suitable place from which it could be obtained. A small amount might be had from Observatory Hill, but the leveling of this hill, except to a small extent, was neither desirable nor advantageous. It was necessary to procure it from the bed of the river. Besides being the most economical method of obtaining it, it accomplished two objects at the same time—the improvement of navigation, and the reclamation of the flats.

The first contract was for dredging a channel 20 ft. deep and about 400 ft. wide, about two-thirds of the spoils to be deposited on the flats between the sewer canal and Easby's Point, and the remainder on that part of them below Long Bridge to a grade of about 6 ft. above mean low tide, the object being to reclaim as much of the flats from overflow as practicable with the funds available.

The plan at first adopted was to dredge the material in the ordinary way by means of dipper and clam-shell dredges, convey it in bottom-dumping scows to a receiving basin and there discharge it. At the receiving basin it was again taken up by a clam-shell dredge and deposited into cars. The latter were hauled to the dumping ground by a locomotive.

This method of doing the work not only necessitated the handling of the material twice, but required the construction of long lines of trestle-work, all of which became useless as soon as the work was finished. The trestle on which the railroad ran was built on piles, most of them about 60 to 70 ft. long, cut off, after being driven, at about 10 ft. above the surface of the flats, and capped with 12 x 12-in. timbers. On these caps longitudinal timbers of the same dimensions were laid, and on the latter the rails. The cars were double side-dumpers and had a capacity of 10 cu. yds. each. They were hauled out in trains of 10 cars each, and the contents of a whole train were dumped at one time. For putting the material on the flats above Long Bridge there were constructed about 13 000 lin. ft. of trestle, including the double-track part at the receiving basin. There were deposited on this section of the flats about 862 872 cu. yds., scow measurement, which gives only about 66 cu. yds. per linear foot of track built. The tracks at the receiving basin were set at about 4 ft. above mean low tide, to facilitate the loading of the cars. From this point the grade of the tracks rose until the level of 12 ft. above mean low tide was reached. Several branch tracks started from near the basin at a low level. This was a faulty construction and required more track than if they had started from a higher level.

Below Long Bridge the track was a single line, and most of the material was dumped from a height of about 12 ft. above the level of the flats; 557 000 cu. yds. were dumped from a length of 7 400 ft. of trestle, which gave about 75 cu. yds. per linear foot. In all, there were built over 20 000 lin. ft. of railroad trestle, and there were deposited on the flats by this process 1 418 771 cu. yds., which, when spread out, covered about 120 acres to a depth of 6 ft. above mean low tide. The trestle, exclusive of rails, must have cost $30 000, or at the rate of about two cents per cubic yard of material handled. After the material was dumped from the cars, it was found necessary to level it down by means of a force pump. A Worthington pump was used for this purpose, the water being forced through a 4-in. wrought-iron pipe, at the end of which a small piece of hose, with nozzle, was attached. This method of leveling the material was not altogether satisfactory. It would level a sharp ridge well enough, but if a large quantity of material had to be moved any great distance, the pump was not effective.

The material was dredged from the river at an average depth, say, of 18 ft. below the surface of mean tide, and raised by the first operation of dredging to a height of about 8 ft. above that level, say, 26 ft. in all. It was then towed to the basin and dropped into it. Again it was picked up and loaded into cars, being raised again about 28 ft. for this purpose. It was then hauled out to the dump, being raised about 6 ft. more in taking it to the dumping ground. The material was thus lifted vertically about 60 ft., whereas the average difference in level between the material in the river and on the flats was only about 21 ft. It will thus be seen that an enormous waste of power takes place in this method of handling such material.

The price paid for material dredged from the river-bed and deposited on the flats in the manner just described was 21.2 cents per cubic yard (scow measurement). It will be seen farther on that this was largely in excess of the prices paid subsequently for the same work done by a different method. The price, 21.2 cents, includes all the profits to the contractor.

Simultaneously with the dredging of the channel and filling the flats, the construction of embankments was begun along the margin. This work it was decided to begin at an early day, as it would afford some protection to the material deposited on the flats in times of freshets, and the early construction of these embankments would enable a better and more economical method to be pursued in filling behind them.

The embankments had to be formed for the most part in water that varied from 2 to 4 ft. deep at mean low tide, corresponding to 5 to 7 ft. at ordinary high tides. In some places the depth was less, and in others more. The material along the lines of the embankments varied. Most of it was a soft alluvial, easily handled, and generally good for the purpose. Some of it was very soft and compressible. Only a small percentage of it consisted largely of sand, and this was not difficult to handle.

The embankments were built in the following manner:

An ordinary light-draught clam-shell dredge would make a cut 6 ft. deep at mean low tide, and wide enough to enable her to work conveniently, depositing the spoils on the side toward the proposed fill.

A low embankment would be thus formed with a berm of about 2 or 3 ft. between the foot of the outer slope and the edge of the cut. In

some places where the water was deep, or the material good, a second cut would be made, widening the trench and depositing the material over and beyond the ridge first formed. Stone was then thrown into the trench, forming a ridge about 9 ft. high with slopes of 1 on 1, as shown on the accompanying sketch (Plate VI). The trench was then further widened and the outer part deepened, using a dredge with a longer boom, or a dredge in connection with a chute carried on a scow which floated alongside and moved with it.

An endless chain dredge was used on a part of the work after the first cut had been made. It gave very satisfactory results. This machine was rigged with an endless chain excavator at the bow, by which the material was lifted to a height of about 12 ft. and then fell into a hopper, from which it was fed into a "conveyor," by means of which it was carried to the place of deposit over and beyond the embankment first formed. The "conveyor" was a line of little cars that formed the links of an endless chain, supported on a frame built on scows moored alongside the dredge, and operated from the latter.

Where there was not enough material in the trench, it was brought there from the channel or some other part of the work in scows. But comparatively a small quantity had to be secured in this way, as on that part of the flats, where the embankments were to be the highest, the water was generally shoalest. No difficulty was experienced in raising the embankments to a height of 12 to 15 ft. above low tide, which was from 14 to 18 ft. above the level of the original bottom.

The slopes which the material took varied with the character of soil and the kind of dredge used. The ordinary clam-shell dredge working without a chute, gave the steepest slopes.

Worked in connection with a chute, the material, softened by handling and aided by a stream of water, acquired such velocity in sliding down the chute that it would sometimes run 200 or 300 ft. beyond the end of it, giving the embankment on that side a very flat slope. The endless chain dredge also gave very flat slopes. The work of forming these embankments was one requiring considerable time. It could not be done rapidly. Time was needed to allow the material taken from the bottom of the river to dry out and become consolidated.

As the work extended over a period of seven or eight years, there was no lack of time. In two or three bad places a slight forward movement took place, but it was not sufficient to cause any serious trouble,

and was due to the building up of the embankment faster than it should have been at those places. The embankments thus formed had an aggregate length of about 8½ miles, and over this long line the material, of which built, varied considerably. Where there was some sand mixed with alluvium, it would dry out and become firm in a short time; in other places where the bed of the river was soft mud, it took a long time to harden. In one place it was only with the greatest difficulty, by going over it frequently and by allowing plenty of time for it to dry out, that the embankment could be gotten to stand at all. The water in this spot was about 8 ft. deep originally, and the bottom extremely soft. Of course, in that case material for the embankment could not be taken from a trench in front of it, as the water was already too deep. The stone was placed in the usual way and material was brought from some other part of the work, dumped in front of the stone pile, and then redredged and deposited over and beyond it.

As before noted, nearly all the embankments were built by depositing a ridge of stone in the trench. This formed a footing for the embankment and a foundation for the dry wall that was afterward constructed, and was a necessity for the most part to protect the embankment from the abrasive action of the waves. The top of the stone pile, being a little above the level of high tide, protected the bank and prevented it from being washed down.

The two banks of the sewer canal, at the foot of Seventeenth Street, were built without stone footings; but in the canal the water was quiet and the wash of the waves scarcely felt.

The construction of a revetment, or sea wall, as it is sometimes called, was not regularly begun until about all the material needed in the embankments had been laid up. This wall rests on the stone pile at the foot of the embankment, and, starting from low-water level, is 6 ft. high, 5 ft. wide at the base, and 3 ft. wide at the top. The face has a batter of 3 vertical to 1 base. The back of the wall is vertical. This wall is laid up with dry stone, quarried on the banks of the Potomac, about four miles from the work. The stone forming the footing of the embankment and foundation of the wall cost from 69 to 95 cents per cubic yard, or an average of about 87½ cents, delivered in place; that used in the wall proper cost $1 70 per cubic yard delivered on the bank, and $1 45 per cubic yard for labor of laying it up—a total of $3 15 per cubic yard, or about $2 80 per linear foot of wall, making a durable and cheap revetment (see drawings).

The formation of the embankment along the margin of the areas to be filled enabled the hydraulic method of dredging to be used, which was a far cheaper and more satisfactory method of doing the work. The first practical application of the pump for transporting the spoils of dredgers to the place of deposit, known to the writer, was about 1867 or a little earlier, in the construction of the Grand Canal at Amsterdam. The dredging itself was done in the ordinary way, by endless-chain dredgers, the material being deposited into a hopper from which it was fed into a pump attached to the side of the dredge and forced ashore through pipes. The pump was centrifugal, 3 ft. 6 ins. in diameter, laid flat with the top on the level of the water and provided with two inlets protected by valves, one in the bottom for the admission of the water, the other on top for the admission of the material to be transported. The pipes were made of wood, with buoying pieces to float them, and connected by leather joints. The diameter of the pipes was 15 ins.

Four dredges working on this principle were employed in 1867 in excavating a part of the Grand Canal at Amsterdam. The largest one is reported to have been capable of transporting about 1 330 cu. yds. of material, consisting of a mixture of clay and sand, in 12 hours. The distance was about 900 ft., and the lift about 5 ft.

General Gillmore, of the Corps of Engineers, U. S. A., in 1872 operated a suction dredge at the mouth of the St. John's River. At that time it was a novel device as applied to dredging. He used a No. 9 Andrew's centrifugal pump, mounted on a steamer, with two 6-in. suction pipes that reached to the bottom of the river. The ends of the suction pipes were armed with knives or teeth, by means of which the material was stirred up and aided in entering the pipes. The material was sand and was pumped with the water into bins, which were built on the boat for that purpose; here the sand settled, and the water ran off. After filling the bins with sand, the steamer was taken out to sea and the sand discharged. General Gillmore states that he succeeded in raising by means of his pump as much as 45% of solid material, but that 30 to 35% was a fair proportion. The height to which the material was raised was but a few feet above the level of the water. Average time worked per day was six hours. Average quantity of sand excavated per hour, 78 cu. yds. Total quantity in 58 working days, 23 868 cu. yds. Average cost, $31\frac{1}{15}$ cents.

The hydraulic dredges used on the Potomac combined the two operations of excavating the material from the bed of the river and discharging it ashore at the desired place in a single operation.

In principle the machine was essentially a combination of the two processes practiced by the Hollanders in 1867 and by General Gillmore in 1873.

The machine consisted of a large rotary pump mounted on a scow-built vessel, 100 ft. long by 50 ft. beam, held in position by means of spuds in the usual way. From the pump, which is located in the forward part of the vessel, a cast-iron pipe leads to the bow and thence down to the bottom of the river. The part leading down into the water is held in a crane which moves about a center from one side to the other over the bow of the vessel, which is rounded to accommodate this movement, and allows the pipe to describe the arc of a semi-circle 60 ft. in diameter. The pipe is arranged with telescopic joints by means of which the length is regulated so that the lower end is kept at the proper distance from the bottom.

Connected with the pump is a discharge pipe which passes out over the side of the vessel and from thence is carried on pontoons to the shore. Each pontoon carried one section of pipe, set on it longitudinally. The joints of the pipe were made flexible by sections of heavy rubber hose, or by ball joints of cast iron. As may be readily imagined, the rubber joints were a source of considerable expense, as they wore out rapidly and were apt to burst under pressure.

The pump was 8 ft. in diameter, of the Von Schmidt pattern; the suction pipe 22 ins., the discharge pipe 20 ins. in diameter. It was operated by two engines, 22 x 24 ins., which were geared directly to the shaft of the pump. Two more engines, 12 x 18 ins., were used, one to run the turn-table carrying the crane, the other the plows or cutters at the bottom of the suction pipe. Two boilers supplied steam. They were 24 ft. long by 6 ft. diameter, and were called 400 H. P. The usual pressure of steam was 90 lbs.

At the bottom of the suction pipe was a hood or bonnet 8 ft. in diameter, shaped very much like an inverted saucer.

A shaft passing through the center of the hood was provided with radial branches at the bottom. These branches, as well as an iron ring connecting their extremities, were armed with knives or plows, which, by the rotation of the shaft, stirred up the material in the bed of the

river, so that the water moving toward the suction pipe carried the solid matter along with it.

The proportion of solid matter to water pumped through the pipes varied greatly with circumstances. The character of the material, the height and distance of the place of deposit, the velocity at which the pump was run, the dexterity of the man who controlled the action of the cutter, and the distance of the hood from the bottom, all tended to increase or diminish this proportion. Under favorable circumstances 30 to 40%, or even more, of solid matter could be carried, but such large quantities did not give good results as a rule. Too much work was thrown on the pumps, rendering them liable to be overpowered. Ten to 20% was easily handled under favorable circumstances, with the engines making 125 to 130 revolutions per minute. The material that had to be dredged varied greatly, as before stated. In some cases it was soft mud; in others, sand or gravel; sometimes mixtures of these, and sometimes the various kinds would be found in layers. Working in soft material, one of these dredges has averaged about 350 cu. yds. per hour for days, the length of the discharge pipe being over 3 000 ft., and the height above the water-level from 6 to 12 ft.

On one occasion one of these machines put ashore material that had been dredged and deposited in a basin near the edge of the fill, averaging as much as 800 cu. yds. per hour. The material was, in this case, alluvium, brought down the river in freshets, mixed with a little sand, the height of discharge being about 10 ft. above mean low tide, and the distance from the dredge to the place of deposit about 1 200 ft. The material had all been well churned up by being first dredged and then dumped into the basin.

These machines were especially adapted to the work of reclaiming the Potomac Flats. The material, when discharged from the pipes, would spread out in low, conical heaps, the lightest particles being carried off to a considerable distance, while the more heavy stuff found a resting place near the exit from the pipe.

Clay would be discharged in the form of balls from 1 to 5 ins. in diameter, this shape being given to the lumps in their passage through the pipes. Boulders as large as a man's head have been forced through them, but such machines are not adapted to handling gravel and boulders. The latter could be forced through the pipes, but not

economically. Mixed with mud or soft clay, a certain proportion of sand, or even gravel, could be handled with facility, but the amount of the latter must not be great. Pure sand could not be handled with advantage. It acted as a blast and cut away the shell of the pumps in a short time.

A leak would thus be started, which it was sometimes very difficult to find. I have seen 1-in. bolts cut almost through in one day by the sand blast inside the pump.

Working in sand, the discharge pipes were apt to fill up so that their capacity was sometimes reduced 60 to 75 per cent. The sand accumulates first on the bottom of the pipe, where it becomes packed and hard, filling up more and more, until the pump can no longer force water through it. The usual method, when it is found that the pipes are filling up with sand, is to pump pure water through them until they are cleared. But they cannot always be cleared in this way. The sand has been known to pack so hard that water forced through them will not clear them. On one occasion this pumping of water was continued two entire days in an effort to clear the pipes, and it failed. The latter had to be taken apart and the sand scraped out. Water flowing through the discharge pipe of one of these machines has a velocity estimated at from 10 to 15 ft. per second, and yet it could not put the sand in motion.

This method of filling low areas saves all expense and trouble in spreading the material out to the required grade, and it packs much better than when discharged from cars or other vehicles for transportation. When deposited from cars, the mud, if originally soft, becomes softer. A thin coat or shell of dry material forms on top, while that below remains in a jelly-like mass for a long time.

The following table gives a summary of the work done in the year commencing July 1st, 1885, and ending June 30th, 1886, of each one of three hydraulic dredges at that time engaged on the work (exclusive of the months of January and February, during which time they did not work).

Much time was lost by reason of breakage, cleaning boilers, moving machine, arranging pontoons and discharge pipes, freshets, and the taking out of obstructions, such as logs and trees, that were frequently encountered in the bed of the river.

It is proper to state that at first the hands were generally green, and

Date.	Dredge No. 1.			Dredge No. 2.			Dredge No. 3.		
	Actual engine-hours.	Estimated cubic yards dredged.	Average cubic yards per engine-hour.	Actual engine-hours.	Estimated cubic yards dredged.	Average cubic yards per engine-hour.	Actual engine-hours.	Estimated cubic yards dredged.	Average cubic yards per engine-hour.
July, 1885	331¼	39 325	118	338½	94 157	278			
August, 1885	205	20 947	102	378	73 266	194			
September, 1885	231¼	38 271	165	224½	45 450	202			
October, 1885	453¾	97 800	216	359	59 375	165	214	25 232	118
November, 1885	341¾	62 282	182	367	60 159	164	330½	45 267	137
December, 1885	443	88 590	200	274	28 287	103	311½	48 348	155
March, 1886	342	76 303	223	303	41 250	136	405	79 842	197
April, 1886	374½	60 049	160	375½	48 287	129	304½	68 188	224
May, 1886	214	35 152	164	364½	50 685	139	267	58 017	217
June, 1886	370	72 442	196	419¼	75 329	180	*182	34 772	191
Totals	3 307	591 131	179	3 403½	576 245	169	2 014½	359 666	179

Note.—The number of cubic yards dredged is taken from the inspectors' estimates as measured *in situ*, and is somewhat less than the actual amount.

much was to be learned from practical experience before the best results could be obtained with the least expense. The proper management of the suction pipe was a matter of no small moment and called into play the best skill and judgment of the operator. In order to do good work it is necessary that the hood at the bottom of the suction pipe be kept constantly at the proper distance from the bed of the river. If it gets too close, too much solid matter is drawn into the pump and may choke it; if not kept near enough, only water may be pumped through the pipes. A vacuum gauge connecting with the pipe is kept before the eyes of the man who regulates the suction pipe, and, by knowing the degree of rarification of the air in it, he is able to control its action. It is an operation requiring skill.

By means of the hydraulic method 5 036 651 cu. yds. of material were dredged from the river-bed and deposited on the flats.

The prices ranged from 12.37 to 15.45 cents per cubic yard.

Measurement was made *in situ* in the river-bed generally, but 1 000 000 cu. yds. were measured by cross-section on the fill.

One of the defects of the Von Schmidt hydraulic dredge is the rigidity of the suction pipe. It is telescopic, but has no flexibility, and even in moderately rough water it cannot be used, as the rolling

* This dredge was burned June 19th, after having worked .65 of that month.

of the vessel is almost sure to break the pipe. For this reason it is only applicable in localities where the water is comparatively smooth.

Another defect is an unnecessary number of bends in the suction and discharge pipe. It is well known that in forcing water through pipes a considerable loss of velocity is sustained at the bends, and that the number of them should be as few as practicable. The number of sharp bends in the pipes of the Von Schmidt machine are unnecessarily great, there being no less than three that could be avoided by a different arrangement.

Still another defect is the want of some appliance to remove logs, trees, etc., that are so frequently encountered in dredging operations. Some of these machines are provided with a small derrick, to pull them out after they are found; but the trouble is in finding them before mischief is done to the machine. They are a great source of trouble and delay when met, and not infrequently cause a breakdown before their presence becomes known. In some places these and similar obstructions buried in the soil are quite numerous, and some appliances should be on hand to detect and remove them. Or, if they be encountered unexpectedly, the suction pipe and the cutters on the end of it should be so arranged that it would not cause damage to the machine.

Another method for putting the spoils of dredging ashore, and used to some extent on the Potomac Flats, was by means of the Riker pump.

By this method the material was raised and discharged into the high end of a long chute, down which it flowed under the influence of gravity and the impulse given to it as it was forced out of the discharge pipe. The material was dredged from the Washington Channel and conveyed in bottom-dumping scows to the pump, which was located close up to the embankment previously constructed.

The pump was a steel cylinder, 7 ft. in diameter and about 30 ft. long. This cylinder sat in a jacket, about 9 ft. in diameter, giving a space of 1 ft. between the two, which space was allowed to fill with water. Near the bottom of the cylinder was an intake or suction pipe passing out horizontally through the jacket. This intake, 36 ins. in diameter, was provided with a flap valve that worked inward. Opposite to the intake was a discharge pipe of the same diameter, fitted with a similar valve that worked outward. This discharge pipe, after passing through the outer jacket, curved upward and was extended to

the high end of a chute, about 28 ft. above the water level. The pump was set in a hole nearly 30 ft. deep and braced to a surrounding platform built on piles. The mouth of the intake was thus nearly 30 ft. below the surface of the water. The material to be forced up into the chute was dumped into this hole over the mouth of the intake. Steam from the boilers, being admitted to the cylinder under a pressure of about 40 lbs., forced out through the discharge pipe whatever was in the pump. The steam being then cut off, a shower of cold water from a tank on top of the pump created a partial vacuum, and an inrush of material at the intake ensued. The mouth of the latter being buried in mud, it filled the cylinder.

Steam was then again admitted and the contents of the pump forced out as before, and the operation continued in a succession of pulsations at intervals of about one minute. The amount of material discharged at one pulsation depended on the amount within effective reach of the intake. It was estimated that about 1 500 cu. yds. could be pumped per hour if material was supplied with sufficient rapidity.

The ability of this pump to handle heavy objects was demonstrated on two occasions: at one time a stone, supposed to be a buoy anchor, weighing 1 300 lbs., and at another time, an iron safe, 25 x 16 x 14 ins., were forced through it.

The chute into which the material was discharged was a large frame-trough supported on trestles, and was about 456 ft. long. It had an inclination of 1 vertical to 25 base. The momentum acquired by the material as it was forced out of the discharge pipe, aided by the force of gravity, was sufficient to carry it to the end of the chute or some distance beyond. It was necessary, however, to keep the machine in nearly constant operation, and to pump large quantities of water, so as to keep the material on the dump in a jelly-like mass so it would spread out. A stoppage of work for a few days would cause it to take a "set," and, after that, the accumulation at the end of the chute would become so great that a change in the location would be necessary.

About 400 000 cu. yds. of spoils from the Washington Channel were put ashore by this machine at a cost, inclusive of dredging, of 13 cents per cubic yard, place measurement.

Another contract was made at a subsequent date for depositing 500 000 cu. yds. by the same method, on another part of the flats, at 14½ cents per cubic yard, but the contract was not fully carried out.

Much trouble arose from the material piling up at the end of the chute, which was caused chiefly by inability to keep up a constant supply.

This method of transporting spoils from the bed of the river was not as advantageous, in many respects, as the hydraulic. The construction of long chutes was expensive; the material did not spread out so well, and the fill was longer in becoming solidified. It is believed that the construction of the chute could have been avoided by using iron pipes. Large quantities of water had to be pumped anyway, and if the pipes had been extended on the fill as it was made, in a manner similar to that practiced in the hydraulic method, the level could have been kept down to the required grade, as the position of the end of the discharge pipe could easily and frequently have been changed.

The total amount of material deposited on the flats up to January 1st, 1893, was as follows:

	Cubic Yards.
By use of ordinary dredges and railroads on trestles..	1 418 771
By ordinary dredges and Riker pump.....	781 118
By ordinary dredges, but mostly taken in close proximity to, and for the purpose of forming, embankments.....	2 200 983
By hydraulic dredges.....	5 036 651
Total.....	9 437 523
More than three-fourths of the above was measured in place. Reducing all to scow measurement, the total would be about.....	10 800 000

The average price all the way through was somewhat less than 15 cents per cubic yard. The average price paid for the hydraulic dredging, which was the most satisfactory, all things considered, was about 14 cents per cubic yard, *situ* measurement. It is difficult to say just what scow measurement of the same material would have amounted to, but it is seldom less than 20% in excess of measurement in place. Converting place measurement into scow measurement on this basis, the price for the hydraulic dredging was only about 11½ cents per cubic yard, scow measurement, which price includes the profit of the contractor. This was but little more than one-half the price paid for the same work done by means of scows and railroads on trestles, the

amount invested in plant in each case being nearly the same for the same amount of work per month accomplished.

From the above it will be seen that the hydraulic method of filling low grounds and marshes is an economical one in many places, and is well worth considering by any one having such work to do. Where the improvement of navigation can be accomplished at the same time, this method has many advantages to recommend it. If it be not applicable for any reason, as, for instance, where the chain of pipes would cross a much-used channel, and they could not be laid on the bottom, it may pay to use one of these machines to put the material, dredged by other means, ashore. Material dredged by the ordinary clam-shell dipper or endless chain method is so cut up and loosened that the capacity of the hydraulic machine for pumping it ashore within a diked space is vastly increased. It is not to be understood that any claim is made that the Von Schmidt hydraulic dredges possess inherent advantages over others. There are other types of similar machines which may do better work. The work done by them on the Potomac Flats was satisfactory, and if others possess superior advantages, it is only an additional reason for using the hydraulic method of dredging wherever it can be practically applied.

Already in many places convenient dumping grounds for the spoils of dredging are becoming scarce. Where the towage exceeds moderate limits, the cost of this item becomes a heavy one, while almost invariably where channels are to be improved there are to be found low marshy grounds near by which would also be improved if the dredged material could be put on them. Heretofore the cost of doing this has been prohibitory. Dumping grounds are sought in the near vicinity of the work, from motives of economy alone. This has caused many places to be used for the purpose which should not be, for the material often finds its way back into the improved channels, or into others which have become impaired thereby.

The filling of marshes in proximity to cities is frequently a desirable thing from a sanitary point of view, while, aside from that, the enhanced value of the land created will, in some cases, more than pay for the cost. At Washington, the value of the land reclaimed is estimated to be worth more than the cost of reclamation.

The amount of settlement that takes place in material of this kind used for filling low places would be interesting if it could be accurately

determined. It was found on the Potomac Flats to vary very much. With a moderate quantity of sand in it, the settlement amounted to little, but where it was pure mud it was considerable and long continued. Material taken from the Washington Channel in 1881, and deposited by means of cars on trestles, had, up to 1884, settled some 2 or 3 ft., but the exact amount is not known. From 1884 to 1891 it settled from 1 to 1½ ft. more. It is safe to say that the settlement on this part of the flats has not been less than 4 ft. in some places in 10 years. The piles of the tramway used for transporting the material remained in a vertical position until some time after the work stopped, but in less than two years from that time they had been pushed over until, in some cases, they were several feet off the line. The material used in making this fill was very soft, and the causeway of Long Bridge held it on the west side. Moreover, the fill was made over the bed of the old swash channel, which crossed diagonally the line of this causeway; consequently, the bed of the river at that place was of recent formation.

At another place below Long Bridge the settlement, as determined by levels carefully taken, varied from .05 to .37 in. A remarkable fact in connection therewith was that the settlement of the material carried with it the piles on which the trestle had been built. The material used in this part of the flats was far better than the other. Some of it was gravel, and most of it was more or less sandy. No record was taken of the penetration of the piles, but it is believed that it did not in the last few blows exceed 1 in. with 1-ton hammer falling 15 to 20 ft.

Reference to the map herewith will show that by the filling of the flats according to the plans adopted, the Washington Channel would be closed at the upper end, making it an arm of the river in which the tide would merely rise and fall, but in which there would be no tendency to clear itself of the sewage, street washings and other refuse that would inevitably get into it. With a view, therefore, of clearing it of this source of pollution, but with no intention of flushing it in the true sense of the term, a large reservoir was designed to occupy a part of the space between Long Bridge and the sewer canal, which reservoir was to receive water on the flood tide from the Virginia Channel and discharge it on the ebb into the head of the Washington Channel, this inflow and outflow to be regulated by means of gates to work automatically, the plans for accomplishing it being left to the engineer to work out. To carry out this idea, a reservoir, excavated to a depth of

8 ft. below mean low tide, was established on Section II. Its area was about 110 acres; as actually laid out it is 111.17 acres. The depth of 8 ft. was fixed upon arbitrarily, but chiefly for the purpose of preventing the growth of eel grass on the bottom (see Plate V).

The mean rise and fall of the tides at Washington is 3 ft., but it is more or less influenced by the winds and the stage of the river in the fluvial portion above the Falls. A rise or fall of 5 ft. is no infrequent occurrence. The mean duration of flood is about five and one-half hours, and of ebb about six and three-quarter hours; but this is also influenced by the stage of the river above. Water being admitted freely at the inlet, the reservoir would receive about 14 500 000 cu. ft. on the average flood tide, or about 29 000 000 cu. ft. daily, enough to replace nearly one-half the entire volume of water in the Washington Channel. This, it was believed, would keep the latter fresh. The reservoir was to be provided with inlet gates, to admit the water from the Virginia Channel on the flood tide, but to close automatically on the ebb, and outlet gates to discharge it into the Washington Channel on the ebb, but to close in the same way on the flood.

After a careful study of the matter during the progress of the work it was found that there was a reasonable probability that the inlet gates might be dispensed with altogether and the connection made with the Virginia Channel by means of an open passage or canal. The fluvial discharge of the Potomac during a large portion of the year is considerable, and it was hoped that this would be sufficient to keep the level of the river at the site of the inlet above that at the outlet, in which case there would be no tendency for the water that entered the reservoir to flow back into the Virginia Channel. It was accordingly decided to build the outlet first and let the necessity of the inlet gates be determined by experience. The wisdom of this was fully justified. The outlet alone has accomplished more than was expected of it.

An examination of the site of the outlet, made during the winter of 1887, showed that, to a depth of 72 to 75 ft. below the level of mean low tide, the soil was a soft, sticky black mud, with an occasional layer below the depth of 45 ft. of sand and mud mixed; that at 72 to 75 ft. there was compact gravel or hard pan, and this was not far from rock. As the structure was to be a heavy one, and inasmuch as any unequal settlement would have been disastrous, it was determined to build it on a pile-and-grillage foundation, the piles being driven to the hard

material, so that they would act in a measure as pillars supporting the weight above. This weight amounted to about 10 tons per pile, the latter being spaced at intervals of 3 and 3½ ft. It is well known that this is not an excessive weight to put on a pile. They are frequently loaded to two or three times that amount, but in this case it was regarded as absolutely necessary that there should be no unequal settlement, and, in order to make sure of this, it was deemed best to found the structure so that, as nearly as practicable, there would be no settlement at all.

The soft nature of the underlying strata was not the only bad feature. In taking the borings marsh gas in considerable quantities was encountered. This gas seemed to be in pockets, and at various depths—from 25 to 65 ft. below the level of mean low tide. At one place when the well pipe struck the gas, the mud and contents of the pipe were thrown out of it with a noise like the discharge of a gun, causing considerable consternation among the men. The gas continued to blow off for hours, resembling the blowing off of steam from a boiler under pressure. The gas was inflammable; in one case it burned for 24 hours continuously; at first, with a flame 8 or 10 ft. long. Gradually the pressure diminished, and finally the flow ceased altogether. It was not believed that this gas would have any deleterious effect on the life of the foundation piles, as other piles used in the bridge, taken up from the ground near by, and where there was every reason to suppose the same conditions existed, were in a perfect state of preservation, though they had been down for at least 25 years.

The reservoir outlet, or sluice gates (Plate VII), as they were designated in the earlier reports, consisted of a masonry structure, or dam, with six arched openings through which the discharge was effected, and connected to the adjacent fill on either side by wing walls. The main head walls of the structure were built of granite, the wing walls of concrete. The faces of the former were vertical, and those of the latter had a batter of 12 on 1. The openings through which the water passes are 6 ft. wide, and 12½ ft. high to the crown of the arch. The gates, which allow the flow to take place outward only, are in pairs, pivoted on vertical axes, and, when open, swing into recesses in the masonry of the side walls. When closed, they butt like the gates of a canal lock on mitres at the bottom and top. Being pivoted at the bottom, and held in a vertical position by a hinge at the top, and always

partially submerged, the friction is so little that the slightest pressure one way or the other, moves them. When the tide begins to rise at the head of the Washington Channel, the gates come out from the recesses and close automatically, shutting off the passage of water from that channel into the reservoir. As soon as the tide begins to fall they open and allow the water to pass from the reservoir to the Washington Channel. The gates need no apparatus to start them from their recesses. They do so automatically, and have done so for several years.

The concrete used in the foundation of the main structure, as well as that in the wing walls themselves, was made of 1 part, by measure, of Portland cement, 2 of sand, 3 of pebbles, and 4 of broken stone.

In order to give a smooth surface to the faces of the walls, the stone was omitted on that part to a depth of about 3 ins., and the quantity of pebbles somewhat reduced. The concrete was rammed in layers of about 10 ins., and, in order to insure good bond between the layers, the top surface of each had spread on it with a brush a thin layer of mortar composed of 1 part cement and 1½ parts sand, immediately before the new one was put on.

The foundation piles of the main structure were cut off at a level of about 12 ft. below low tide and capped by 12-in. timbers secured by notches 2 ins. deep, and drift bolts. A second set of 12-in. timbers crossed the first at right angles, and the spaces between them, as well as the spaces around the heads of the piles for a depth of 2 ft., were filled in with concrete.

The pile and grillage foundation was constructed within a coffer-dam. The dimensions of the latter were fixed at 100 x 80 ft., in order to allow of the construction at the same time of about 30 ft. of each wing wall.

The depth of water at the site was from 4 to 6 ft., and, as the piles were to be cut off at a level of about 12 ft. below low tide, a dredge was sent in, to excavate a part of the material before the coffer-dam was built. It is probable that it would have been better not to have done this. The excavation made by the dredge cost but a fraction of what it cost to take the material from inside the dam after the latter was built, but, on account of the soft nature of the bottom and the disturbance due to a dredge working in it, the material was so much softened

that the top strata became about like jelly and gave great trouble afterward in holding the dam.

After the hole was dug by the dredge, a working platform was constructed on the north side and a tramway to it from the shore.

The driving of the foundation piles and the construction of the dam were then commenced and carried on simultaneously. The dam was built by driving two rows of piles 8 ft. apart, the piles of each row being 3 ft. apart. To these were fastened the wale pieces, one near the surface of the river-bed, the other near the top of the dam. The sheet piling was 3-in. pine, tongued and grooved, and driven about 18 ft. into the mud. Stay rods 1 in. in diameter were passed through each alternate pair of piles, and held in place by washers. The space between the sheet piling was then filled with clay puddle. Within the interior of the dam, a second row of piles was driven at a distance of about 12 ft. from the long sides, to help support a working platform and to stiffen the coffer-dam which was braced against them.

The dam was pumped out in 12 hours by means of a 6-in. centrifugal pump, but, as soon as this was accomplished, the four sides began to bulge inward, the corners remaining fixed. The movement was slow, but it was found to be continuous. The north and east sides soon came in at the middle about 2 ft. The south and west sides moved less, but all moved inward to a considerable extent, threatening the destruction of the dam. The question then arose whether to allow the dam to fill again and strengthen it before pumping it out a second time, or to try to hold it as it was. It was thought that by bracing the sides from one to the other on the interior, it could be held until the foundation piles were cut off and capped. Struts were accordingly put in from the east to the west side, and the north and south ends were braced by diagonals. After the dam was strengthened by bracing, the excavation of the interior began, but the bulging of the sides continued.

This developed leaks, though at first the dam was comparatively dry. Additional puddle was applied where needful, to supply what sank into the mud; but in some places it sank as fast as it was added, the sheet piles spreading at the bottom. Notwithstanding all efforts to hold the dam, it continued to move inward slowly.

It was then determined to drive a row of piles as close together as possible along the outside of the east and north faces. These piles were 60 ft. long and were driven till the tops almost touched water. A

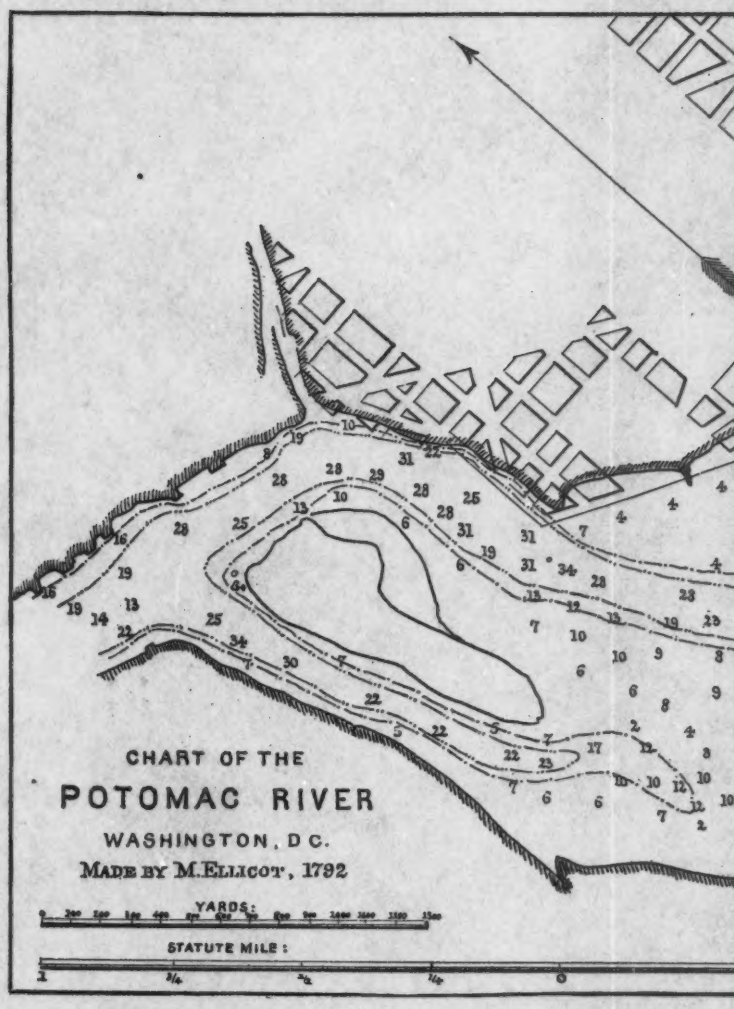
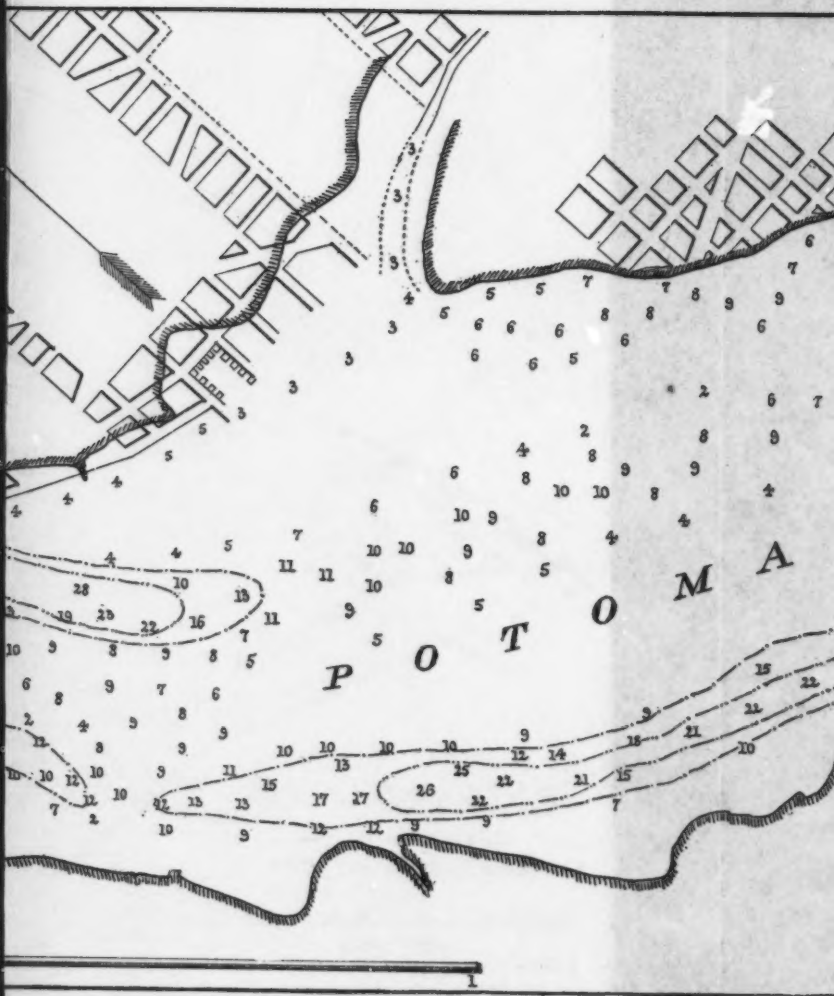
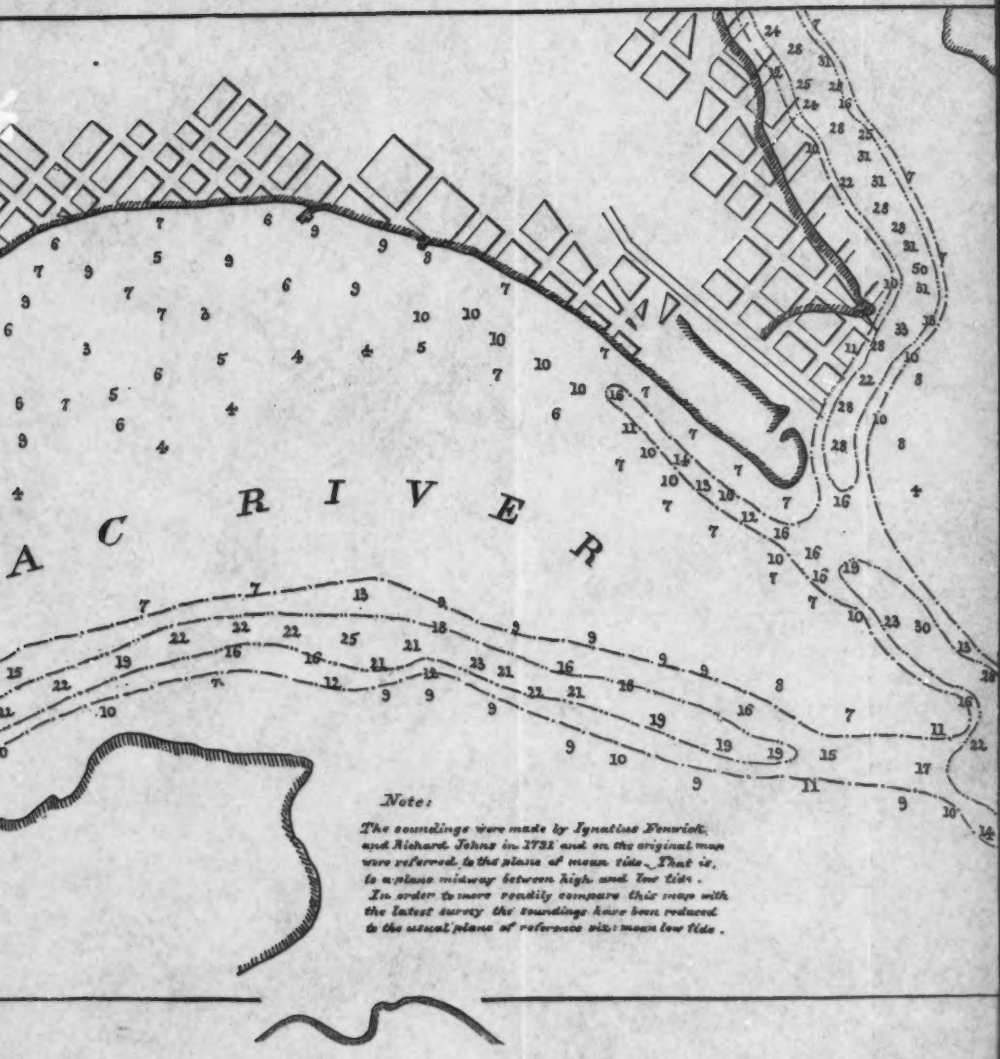
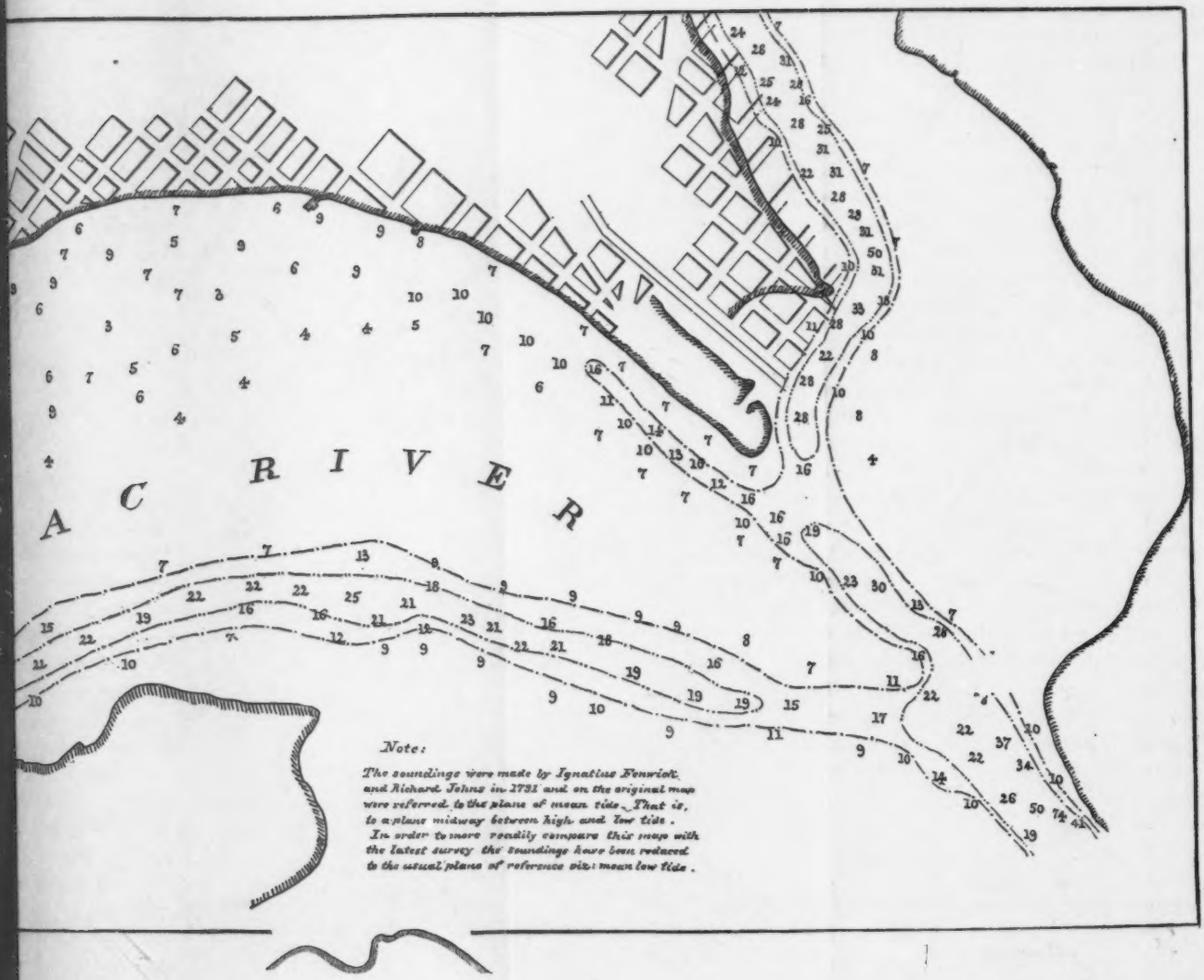
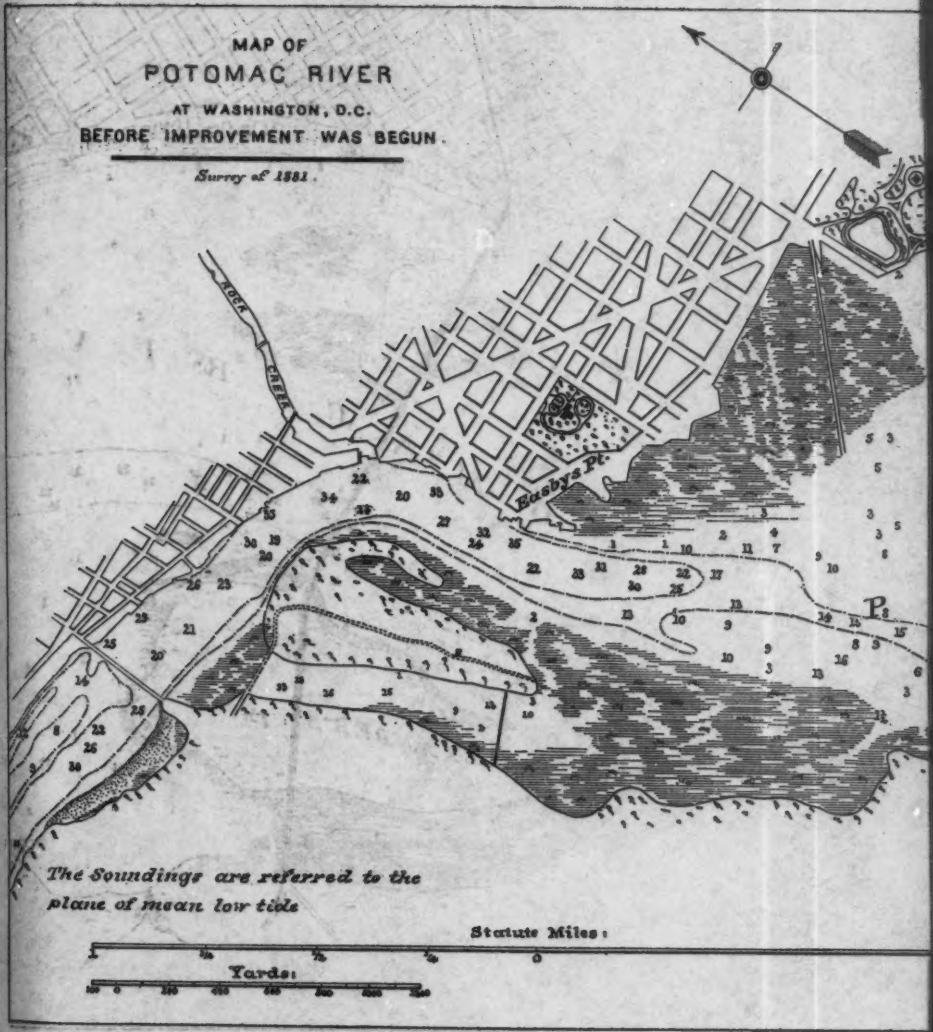


CHART OF THE
POTOMAC RIVER
WASHINGTON, D.C.
MADE BY M. ELLICOT, 1792
YARDS:
STATUTE MILE:

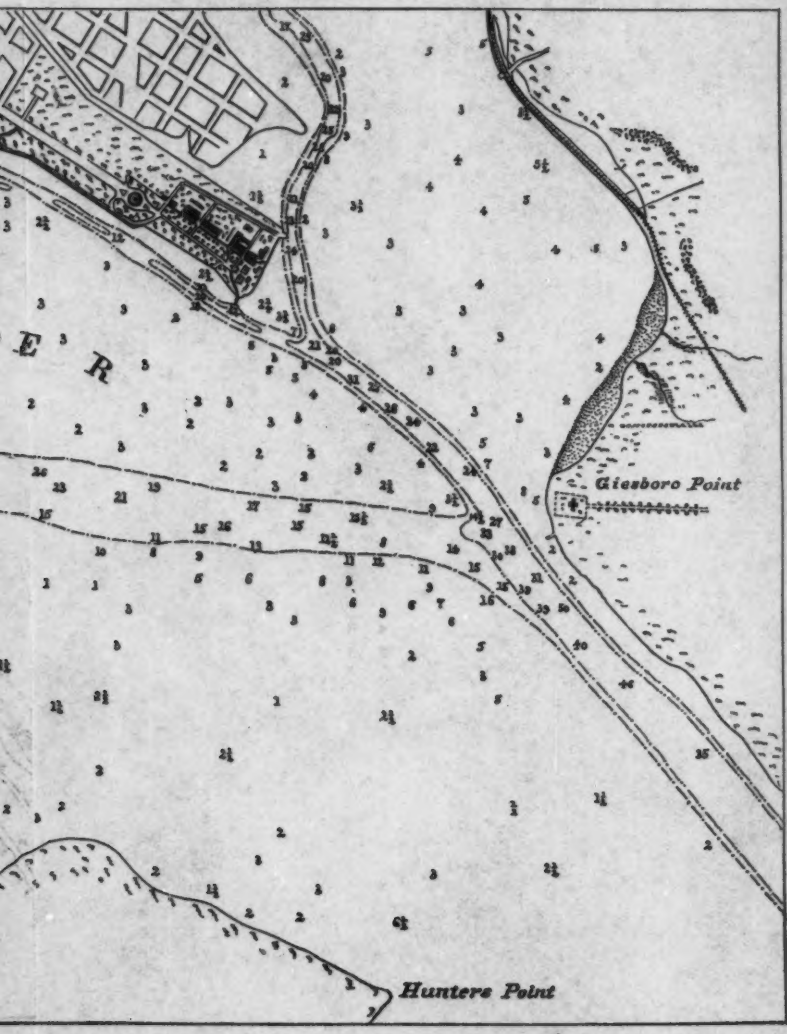

POTOMA
1


A C R I V E R
Note:
The soundings were made by Ignatius Fenwick, and Richard Johns in 1731 and on the original map were referred to the plane of mean tide. That is, to a plane midway between high and low tide.
In order to more readily compare this map with the latest survey the soundings have been reduced to the usual plane of reference viz: mean low tide.


A C
R I V E R
Note:
The soundings were made by Ignatius Fenwick and Richard Johns in 1731 and on the original map were referred to the plane of mean tide. That is, to a plane midway between high and low tide. In order to more readily compare this map with the latest survey the soundings have been reduced to the usual plane of reference viz: mean low tide.

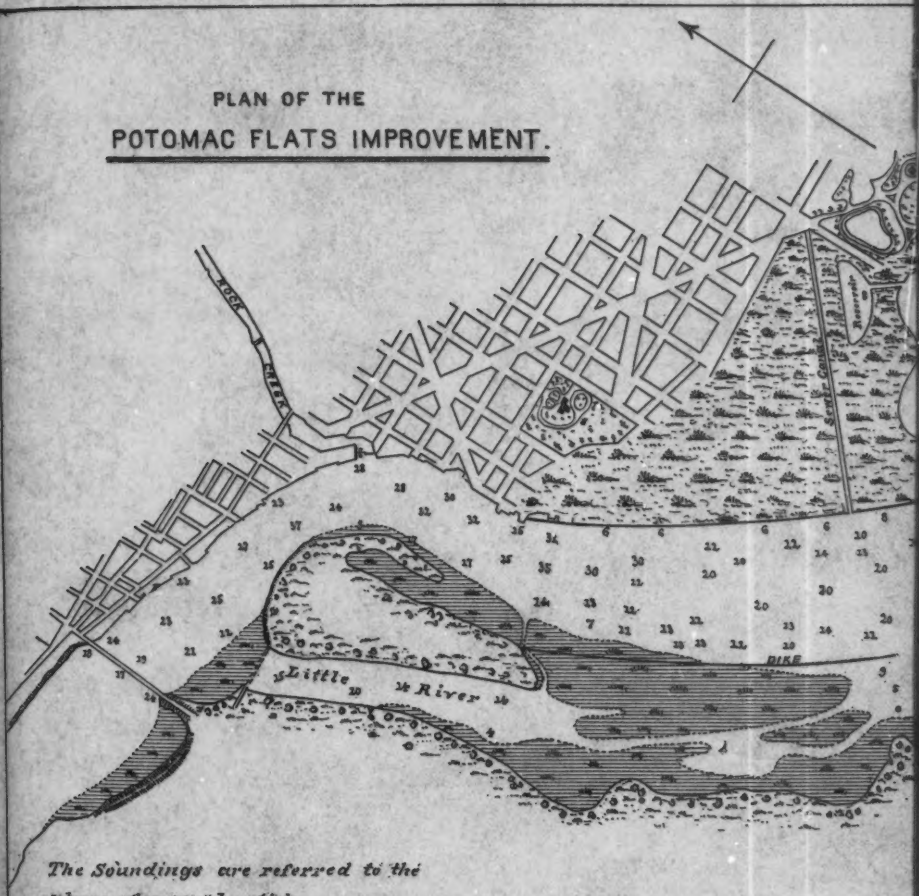

MAP OF
POTOMAC RIVER
AT WASHINGTON, D.C.
BEFORE IMPROVEMENT WAS BEGUN.
Survey of 1881.
ROCK CREEK
Easbys Pt.
The Soundings are referred to the plane of mean low tide
Statute Miles:
Yards:

P O T O M A C R I V E
ALEXANDER'S Id


Glenboro Point
Hunters Point

PLAN OF THE

POTOMAC FLATS IMPROVEMENT.



The Soundings are referred to the plane of mean low tide

Statute Miles

Yards

TIDAL
RESERVOIR
Sewage Canal
Sea Wall
Long Bridge
Virginia
Channe
Gravelly Pt.
DIKE
Sycamore Pt.
ALEXANDER'S
ISLAND

PLATE V.
TRANS. AM. SOC. CIV. ENGRS.
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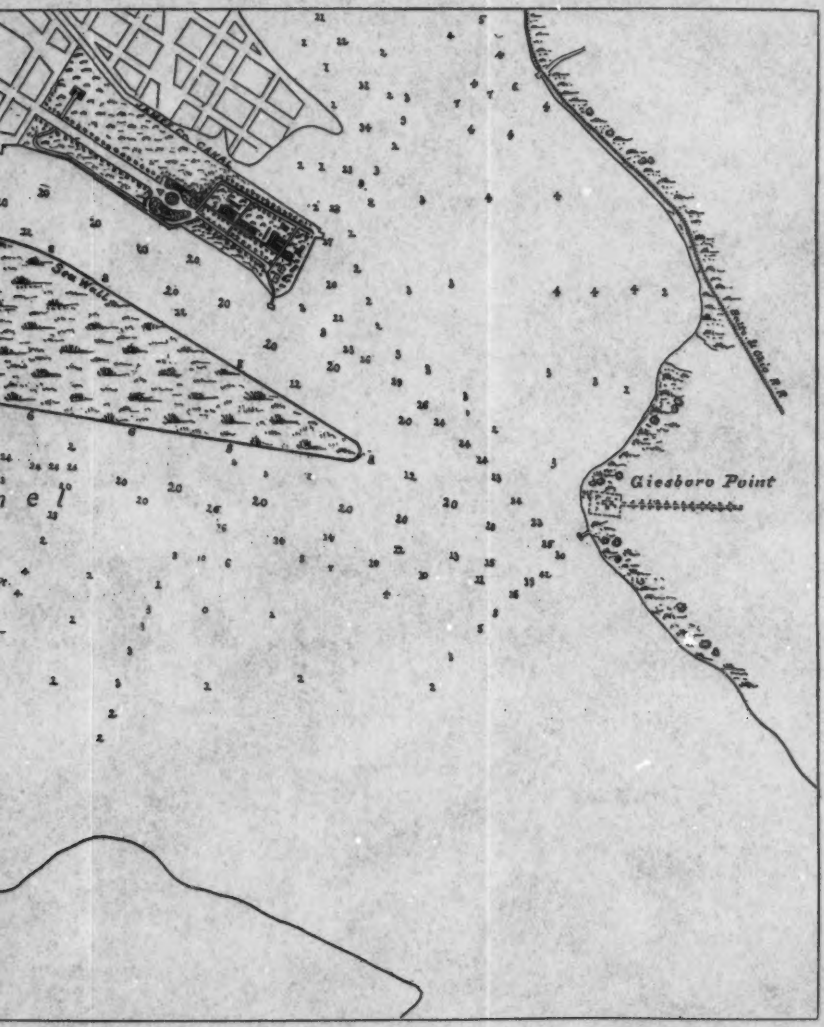
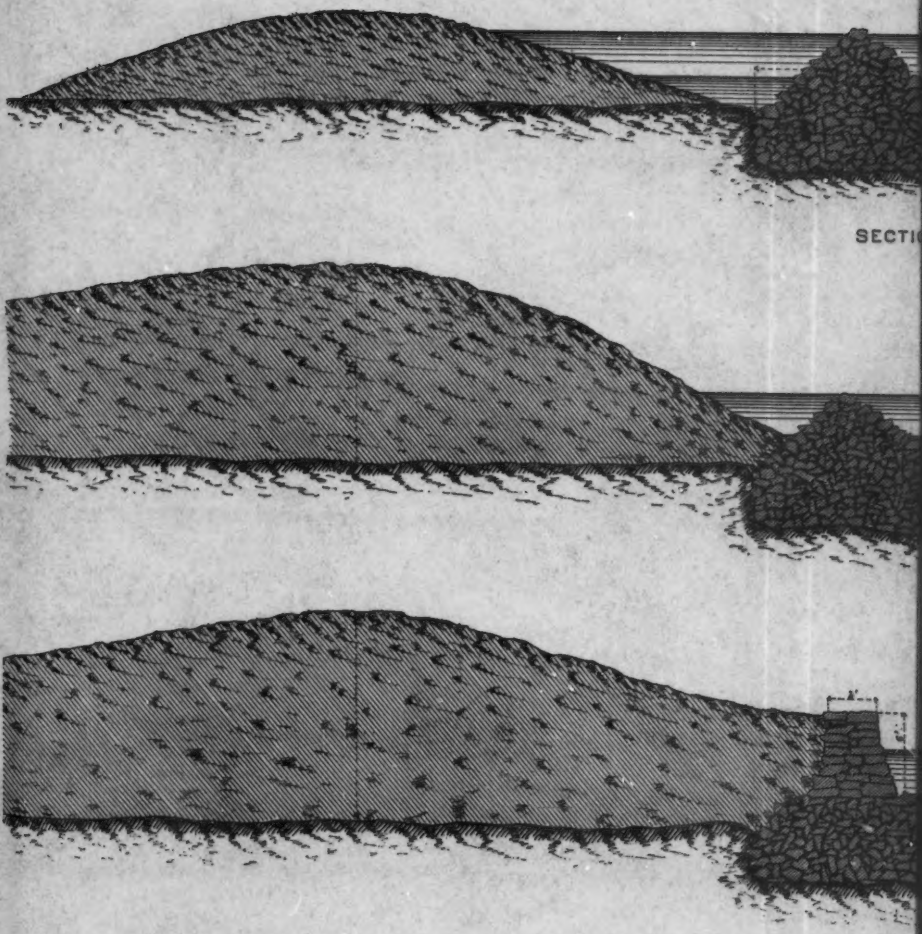
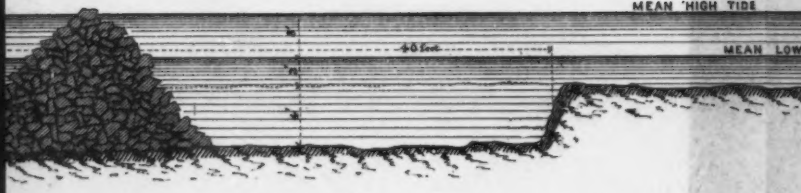
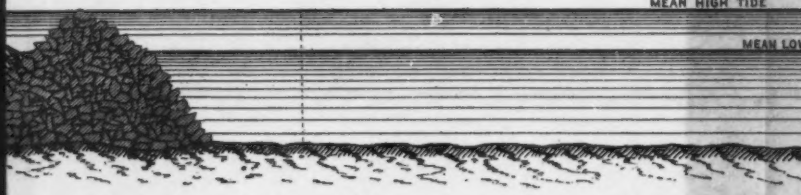




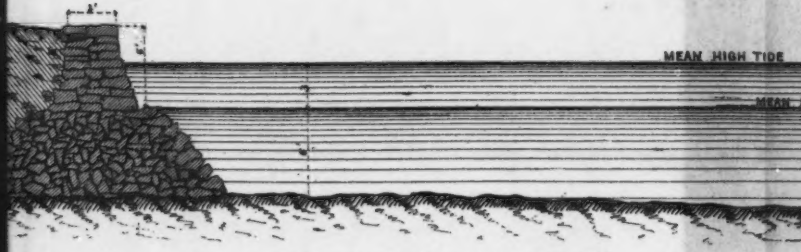
Scale 1 to 100



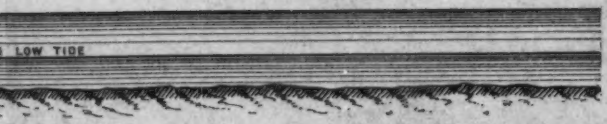
SECTION TROUGH FIRST CUT, WITH STONE FOOTING IN TRENCH.



HIGH EMBANKMENT WITH STONE FOOTING.

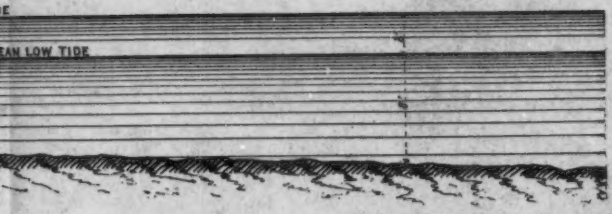


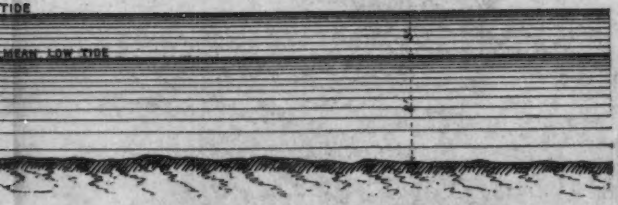
SECTION TROUGH FINISHED WALL

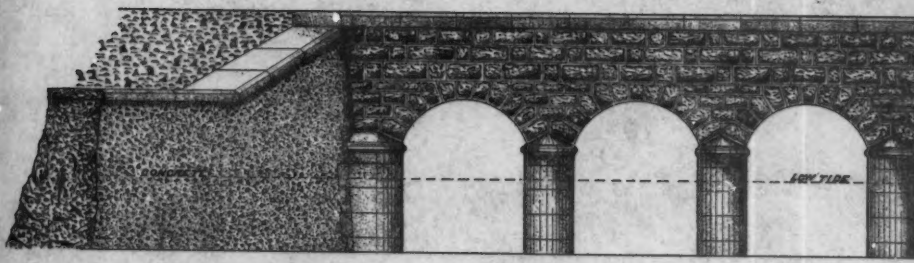


H.

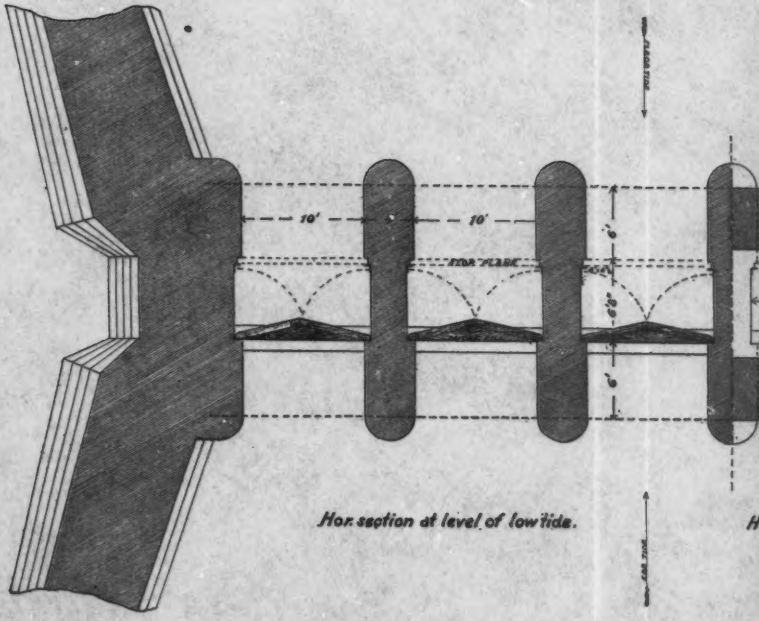
RECLAMATION OF POTOMAC FLATS.





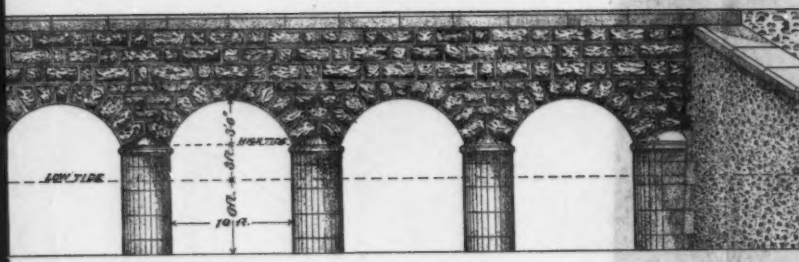


Front Elevatio

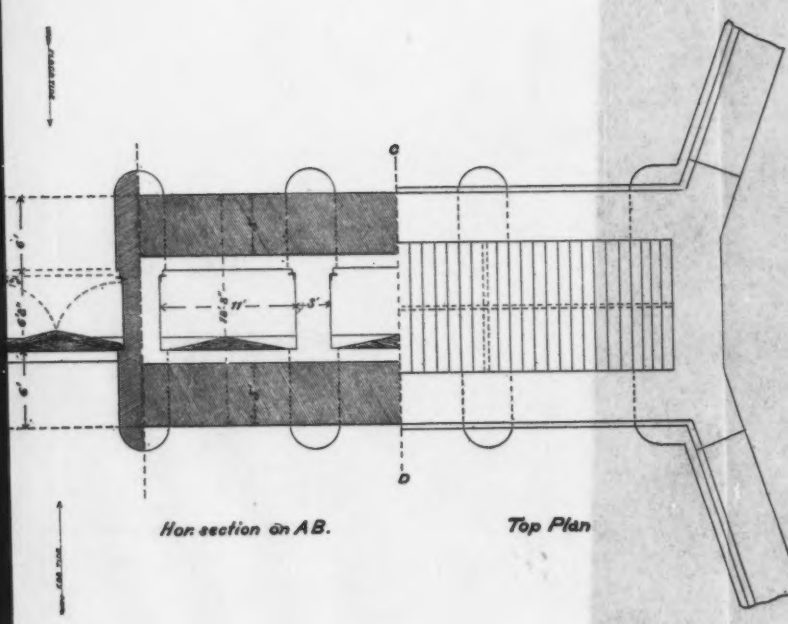


Hor. section at level of low tide.

H



Front Elevation



Hor: section on A B.

Top Plan

PLATE VII.
TRANS. AM. SOC. CIV. ENGRS.
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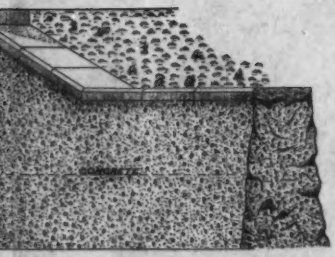
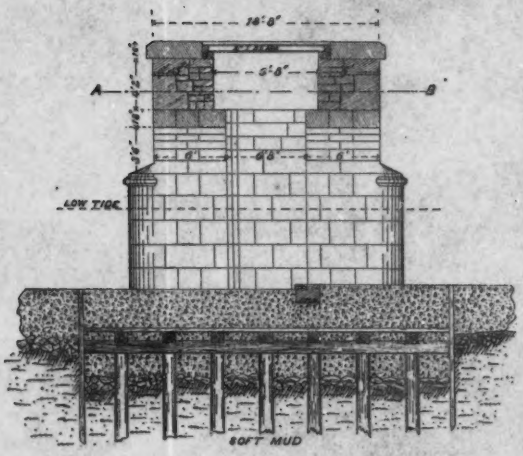
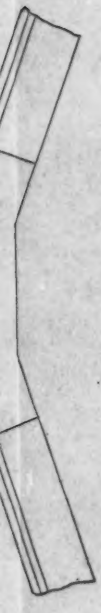
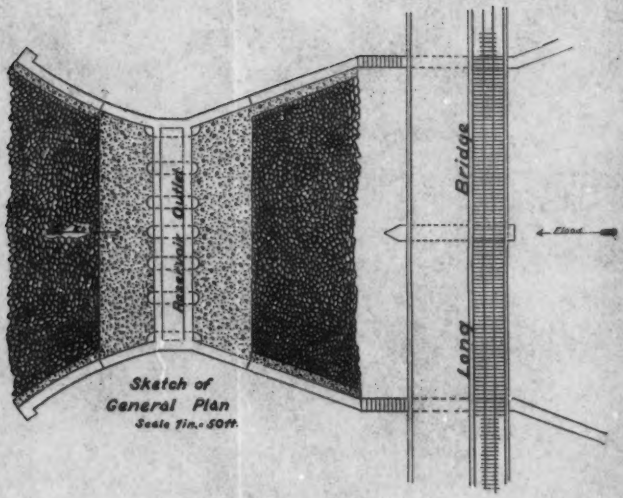
HAINS ON RECLAMATION OF POTOMAC FLATS.





Vertical Section on C.D.
gate removed.





Sketch of
General Plan
Scale 1in.= 50ft.

second row was afterward driven along the inside of the same faces of the dam. More bracing was also added, and the movement was finally arrested. The excavation which had been begun was quickly finished. The piles were cut off and capped with the grillage timbers. When this was done, all danger was over, as there was then something to make fast to; whereas, before, everything seemed to be in motion. Measurements taken showed that the north side of the dam came in at the middle about 6 ft. and the east side considerably more.

Some of the strut timbers were pressed into the piles several inches, and in two cases where struts abutted on opposite sides of the same pile, but one slightly above the other, as in the annexed sketch, the pile between the ends of the struts was sheared off.

After the foundation piles were capped, no further difficulty was experienced in holding the dam. But the treacherous nature of the bottom indicated that great care would have to be taken with the wing walls so that they would not be forced in when the earth filling was put in behind them.

The top of the wing walls where they join the head walls of the outlet are of the same height as the latter, and from there slope off to the level of 6 ft. above mean low tide, which is the general height of the protective wall of the fill. After the experience had in putting in the foundation of the outlet, it was determined to construct an apron of concrete about 4 ft. thick, on a pile-and-grillage foundation extending from wing wall to wing wall within the entire space enclosed by the dam, and to cut off the latter at the level of the surface of this concrete, leaving all that part of the dam below that surface in the ground. The concrete wing walls were afterward extended, giving them a length of about 100 ft. on the up-stream and about 80 ft. on the down-stream side of the outlet.

In order to brace the foot of the wall against the pressure of the earth fill behind them and to more nearly balance the pressures on the two sides, the space between them was excavated to a depth of about 10 ft. and loose stone thrown in, forming a stone floor about 4 ft. thick. This appears to have answered the purpose very well; there has been no tendency of the walls to bulge inward thus far, and by

filling in behind them, gradually, it is believed there will be no trouble from this source.

After the reservoir outlet was constructed, the Baltimore and Potomac Railroad Company built a bridge within about 120 ft. of it, to take the place of a part of the old Long Bridge that spans the Washington Channel. The bridge consisted of two plate-girder spans of about 80 ft. each, resting on one pier and two abutments.

The wing walls of the abutments extended on the up-stream side so as to connect with the wing walls of the reservoir outlet, and on the down-stream side they were to unite with the sea wall protecting the filled area. The abutments were well built of brown-stone masonry resting on a pile-and-grillage foundation. On filling the approaches with earth, the south abutment settled 18 ins., while the down-stream wing wall moved out about 4 ft. This fact is referred to, to show that great care was necessary in the construction of a heavy structure like the reservoir outlet in that treacherous soil, and as a justification of the apparently extraordinary precautions taken to insure its stability.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

690.

(Vol. XXXI.—January, 1894.)

RAILROAD LOCATION.

By MICHAEL L. LYNCH, M. Am. Soc. C. E.

READ OCTOBER 18TH, 1893.

WITH DISCUSSION.

The subject of railroad location from the nature of the case is rather a difficult one to handle through the medium of a professional paper, as it will admit of no fixed or inflexible rules, and it would be manifestly unwise to lay down any such for the guidance of an engineer on that class of work. The writer believes that a discussion of the general principles involved in connection with a résumé of the best modern practice would be of more practical value than any other way in which the subject could be treated.

Reconnaissance.—In the following discussion, a case is assumed where it is desired to connect with a line of railroad two cities, say 250 miles apart, with several intervening towns between them, which it is necessary or desirable that the road should pass through.

The first thing in order is evidently a reconnaissance of the country between the objective points, as a preparation for which the engineer should procure the best general map of the country available, together with such detail county and township maps as can be procured.

A study of the general map will usually show the existence of two or more possible routes, besides affording a knowledge of the main drainage of the country, which latter it is very necessary the engineer should become thoroughly familiar with, as also the tributary drainage as the work progresses. From such an examination he can also approximately determine where he may expect the steepest gradients, as the divide between two main drainages is never equidistant between the streams, which is readily determined by the location of the heads of the tributary drainage and their distance from the main stream or river into which they discharge; the nearer the divide to one of the streams, of course the steeper the slope on that side. In this connection the writer desires to draw attention to a peculiarity that has come under his observation and which he has never seen noted, to wit:

I.—In a stream flowing east or west through a country, the south slope of the valley is generally steeper, rougher, and more broken than the north slope, the latter being the smoother slope and with a gentler ascent out of the valley going north than descending into it from the south.

II.—In a stream flowing north and south, the east slope of the valley is invariably steeper, rougher, and more broken than the west slope, which latter is the smoother and affords a gentler ascent out of the valley going west than descending into it from the east.

In other words, the engineer will find it more difficult to get a line down into a valley from the south in the first case than in leaving the valley going up the north slope; the same applies to an east and west line in the second case. He will find it steeper and more difficult in getting down the east slope of the valley than in getting up the west slope, and where a line follows the valley of a stream, as in the first case, the smoother and better ground will invariably be found along the north bank; and along the west bank, in the second case, where a line occupies the slope or valley of a stream running north and south. A slight effort of memory will no doubt tend to remind any one of the existence of the above general law, it being of course more marked in some instances than in others, and being less noticeable where the streams in their general direction depart from an east and west and north and south course. It applies even on a large scale, as the Pacific slope is much steeper, more abrupt, rugged and broken than the eastern shore of the Continent.

There is possibly some geological reason why this condition should exist, probably something connected with the rotation of the earth on its axis during the formative state, which the writer will leave scientists to explain; he mentions the fact in passing, as having come under his observation and being worthy of note by the locating engineer.

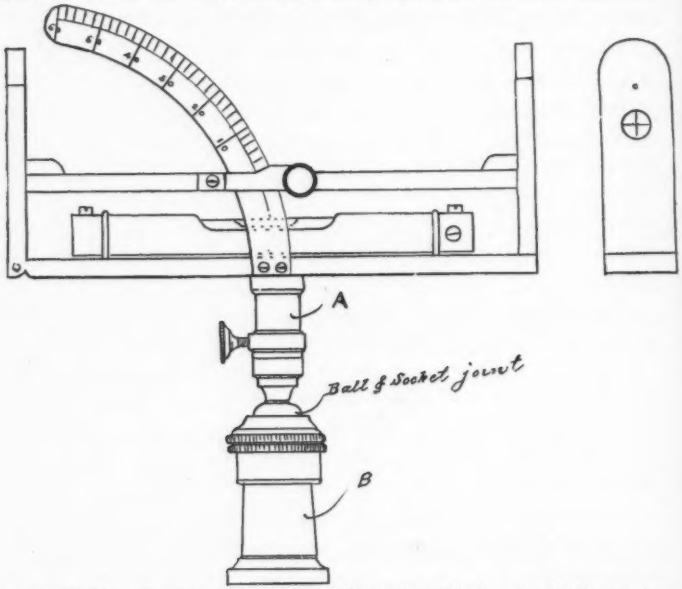
The manner of proceeding with the actual work of the reconnaissance will, to a certain extent, depend on the nature of the country operated over. A well-gaited saddle horse will be a great advantage, as much of the work can be done on horseback and a large scope of country rapidly examined. It will, of course, be necessary for the engineer to dismount and carry a line through on foot where very broken ground, dense brush or other obstacles interfere, leaving his horse to be led around by a man employed to accompany him for that purpose.

The usual portable instruments will of course be necessary in such an examination, but much will depend on the engineer's skill and familiarity with their use, as also on his natural judgment of country. This faculty, as is well known, is possessed by some men to a very marked degree; it enables them to keep track of their position with reference to the country previously passed over and to memorize its general features to such an extent that, after such an examination, the mind seems to absorb such a general knowledge of the country, its drainage and general topography, that a mental map of it is available when desired.

The instruments carried on such a trip are usually the pocket compass, hand level and aneroid barometer. The latter is to be used with much care and judgment, otherwise, owing to changes of temperature and meteorological conditions generally, the results obtained would sometimes apparently make the hills lower than the valleys, and water to run up hill; two aneroids accurately rated and compared, and read at the same hours by different observers within reasonable distances apart in settled weather, will usually give reasonably accurate results as to the difference of elevation between the points where the readings were taken, or the relative elevations of two or more gaps or depressions in a ridge can be determined with reasonable accuracy in settled weather by a single instrument in the hands of a skillful observer.

As a rule the determining of the feasibility of surmounting certain

difficulties at governing points, such as getting over a certain ridge and down the other side on a practicable gradient, is where the leveling instrument is most needed. The writer uses and recommends for that purpose a small hand level as per accompanying sketch, with sights like



a surveyor's compass, and with graduated vertical arc which can be set to any gradient desired, and will readily determine whether the maximum gradient is practicable along a given slope, and what the approximate depth of summit cut would be. Such an instrument would probably have to be made to order, as it is not catalogued or illustrated in any of the instrument-makers' manuals with which the writer is familiar; the ordinary hand level is generally used on this kind of work, and in the hands of a skillful observer will, of course, give good results.

In a reconnaissance of the kind under consideration, several governing points will present themselves—the crossing of certain ridges and of important streams, and the touching at certain towns. As a rule it will be found advisable to determine the lowest saddle or gap in the different ridges and the best crossing of the large streams in the gen-

eral direction of the line, together with the most suitable entrances and exits from the towns, the location of the various intervening sections of line being laid with reference to these governing points, and being more or less subordinate to them.

The reconnaissance being made between the two objective points on one of the possible routes selected, it will be advisable to examine a return line by another route for the purpose of comparison, and, in broken or very difficult country, to examine several routes in order to acquire a thorough knowledge of the country, as portions of the various lines examined may be combined and adopted on the final location.

Sometimes a good line can be had along a ridge where it is wide and flat and the minor drainages starting from it head some distance on either side, away from the divide; at other times a ridge line will be found impracticable owing to its narrowness and generally broken and crooked character, caused by the minor drainages heading on either side of the general trend of the divide.

The writer would recommend the making of copious notes and sketches during the progress of each day's work; this necessity will become quite apparent when the actual work of locating is undertaken.

The result of a thorough reconnaissance as above outlined, when carefully platted and sketched in, will show such a practically correct and useful topographical map of the country as will be quite a surprise to one not familiar with this class of work, as the lines run with a hand compass and the distances determined by timing a well-gaited horse give much more accurate results than one would ordinarily suppose to be attainable under such circumstances.

In this connection the writer desires to draw attention to the importance of a thorough reconnaissance before starting the instrumental preliminary and location surveys; otherwise the best line in a country may be overlooked and an inferior and more difficult general route adopted, which, no matter how skillfully the actual detail work of location might be performed, would be inferior to the omitted line for purposes of railroad operation.

Preliminary Survey and Final Location.—The reconnaissance being complete, the next thing in order would be the organization of a party or parties to take the field and run the preliminary lines and the final location.

The general organization of such parties is usually similar, but may differ somewhat in detail in different localities.

In thickly settled sections of country the reprehensible practice is sometimes adopted of starting the party out without a camp outfit, providing for their subsistence and accommodation at the different farmhouses along the line. This method will not be further referred to than to say that it is an arrangement which, at best, cannot be too strongly condemned for various reasons too obvious to need mention.

A party properly organized for preliminary or location survey in ordinary country should have a proper equipment of not less than three good teams and wagons, tents to accommodate the rank and file of the party, office tent for the engineers, and one to answer for a cooking and dining tent, with saddle horse for the locating engineer and one for the chief of party, although the latter is not indispensable. The party should be full-handed and include draughtsman and topographer, together with cook and teamsters; the teams in addition to moving camp, to be used in taking the men to and from their work on the line and taking lunch to them at noon.

It will be found good practice to transport the men to and from their work, as thereby more hours of work can be obtained from them and they will be fresher and in better condition to perform the work required of them.

In conducting the preliminary survey, it is, of course, desirable that the line should be run as close to where the final location would lay as possible, the chaining to be carefully done, and all angles turned off on the vernier of the transit; in other words the preliminary line should be accurately run as the location is built upon it, and inaccuracies in the preliminary lines are sure to cause trouble and annoyance when it comes to final location.

This also applies to the work of the topographer, as the accuracy with which the contours are laid, and streams, buildings, etc., located upon the preliminary map, has a direct bearing upon the case and the accuracy with which the final location can be made. The topographer will find the elevation of each station as obtained from the level notes of great advantage to him in properly laying on his contours, and with a judicious use of the tape line and slope level should be able to furnish an accurate topographical map for several hundred feet on either side of the line, including the general course of streams crossed, etc.

For such a survey as the one under consideration several preliminary and spur lines may have to be run, and while to the uninitiated the work might appear to be making slow progress, still it is, nevertheless, good practice to thoroughly develop the country by means of preliminary lines before deciding on the final location. This the engineer sometimes finds difficulty in doing, as, owing to the ignorance of those who should be supposed to know better, the attempt is often made to force him to establish a line without giving him the necessary time to properly develop the country, the result being that many roads are to-day suffering from the effects of mislocation, caused by crowding the engineer on his work, and failing to accord him the necessary time to properly develop the country. The evil effects of such a practice are continuous, in the increased cost of maintenance and in the operating expenses of moving trains over steeper gradients than there is any actual necessity for.

In this connection it may be well to say, that, counting the time occupied on preliminary and location surveys, wet days, etc., one mile a day of finished located line is a fair average in an ordinary country, partly timbered and partly open; more than this can of course be done in a smooth open country, and not so much in a very rough broken country.

The preliminary lines having been completed, and one of them, or a combination of several of them, having been decided upon as the most feasible route to adopt, the work of final location is proceeded with, the tangents and curves of the proposed location being first projected on the carefully prepared topographical map of the preliminary lines before laying off in the field. It often happens, however, that the location so projected can be improved, and the best practice, in the writer's opinion, is to recognize the possible necessity for such change and be prepared to make it in the field when necessary as the exigencies of the case demand; in other words, no cast-iron location can be projected on a preliminary map in the office, no matter how accurate such a map may ordinarily be, as such lines are liable to be susceptible of improvement in part when it comes to actually laying them on the ground. There is no royal road to railroad location. It cannot be done from a telegraph key, or a typewriter desk. To obtain the best results the work must be actually executed on the ground by one especially skilled in that branch of engineering.

A scale of 800 ft. to 1 in. is a convenient scale for preliminary maps upon which the location can be projected ordinarily. On difficult sections of line the writer has found it convenient to increase the scale for such portions to 400 ft. to 1 in., projecting the location on it, taking scale and protractor on the line, prepared to re-project and re-run the line until the best result obtainable in the country is attained. It will also be found useful to have a small strip of profile paper along, so that the level notes of some doubtful or difficult piece of line can be plotted as the work progresses. In general, the more experience the engineer has on this class of work, the more careful he is to take every advantage and precaution to get the best line the country affords, recognizing the fact that there is a best line in every country, and that it is his province and his duty to find it; and, strange as it may appear to the layman, the skillful locating engineer can tell unerringly when he has found the best line in a country.

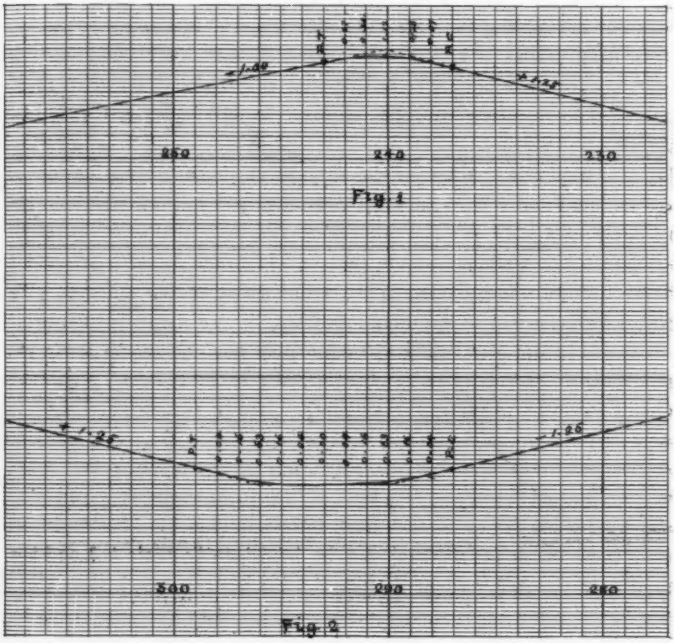
In regard to curvature and grades it is assumed that a certain maximum has been determined upon, which must not be exceeded. In this day of rapidly increasing speed it is desirable that no reverse curves should exist—a few stations, at least, of tangent between curves of different directions being a necessity to admit of the engine and leading cars of a train straightening themselves out before entering the curve ahead. Of course, the more of such tangent the better. Heretofore transition curves were rarely used, but, owing to the increased speed that now obtains, they may be considered a necessity where the curvature is at all sharp.

"Broken-back" curves, as they are called, should be avoided—that is to say, two curves in the same direction with a short stretch of tangent between them; they are "bad form," to say the least, and one curve covering the ground and eliminating the short stretch of tangent can usually be found with a little extra labor.

In compensating a gradient for curvature it is now generally conceded that a compensation of .04 ft. per station per degree of curve is about right, and at the junction of two gradients on a summit or the bottom of a depression, it is very necessary to round them off by vertical curves. The two gradients can be run together, as in Fig. 1, and a vertical curve run in connecting them by a simple calculation, as follows:

An ascending grade of 1.25%, Fig. 1, meets a descending grade of

1% on a summit. The ordinates of a curve can be calculated by taking one-half the sum of the rate of grade per station, regardless of algebraic signs, as the ordinate of correction at the apex, one-fourth of that ordinate as the correction at the first station on each side of the apex, and one-fourth of this last ordinate as the next correction, and so on.



For example, the ordinate at the apex, Station 240, would be $\frac{1.25 + 1.00}{2} = 1.12$, one-fourth of which $= 0.28$ would be the ordinate for Stations 239 and 241; one-fourth of this last ordinate $= 0.07$ would be the ordinate for Stations 238 and 242, after which Stations 237 and 243 could be assumed as the beginning and end of the curve. This would result in a curve 600 ft. in length, and will be found to give a good practical result in connecting two such gradients.

Fig. 2 is an example of two 1.25% descending gradients in connection with a level grade of six stations. By the same rule the ordinate for Stations 290 and 296 would be $\frac{1.25 + 0.00}{2} = .63$, and for the stations, on either side, .16 and .04, etc., making Stations 287 and 299 the beginning and end of curve which results in a vertical curve 1 200 ft. in length. The writer prefers a stretch of level grade connecting two descending grades, as in the last example, in preference to connecting the gradients direct, as in the case of the two ascending grades, Fig. 1. The calculations for establishing vertical curves in this manner are so simple that they can be performed mentally. The resulting curves have been found to give good practical results in operation.

It is desirable by all means that vertical curves should be run in at the foot of all steep gradients, their absence being a fruitful source of derailment at these dangerous points (generally over some opening), owing to the tendency of the rear cars of a train to bunch or crowd those in front where a suitable method of transition has not been provided for between two opposing gradients.

It will no doubt be quite apparent that some of the methods set forth above, especially in connection with reconnaissance, would be inapplicable or unsuitable in a country already covered by complete topographical surveys, such as the ordnance surveys of Great Britain, or the other elaborate government surveys of the older and more thickly settled European countries of which elaborate topographical maps are available, which materially lighten the labors of the engineer, and from which the location can be intelligently projected and the line approximately laid in the office. The system outlined has more particular reference to such countries as America, Russia and others of large extent, where extensive areas are yet uncovered by such elaborate topographical surveys.

In this paper the writer has endeavored to give his views in a general manner on this important subject, without attempting to lay down any inflexible rules, being aware of the fact that "circumstances alter cases."

DISCUSSION.

C. E. MOORE, M. Am. Soc. C. E. (by letter).—The literature of railroad location is quite scanty. Especially is this true of that which has been written by practical men. For this reason a paper like that by Mr. Lynch is very welcome, and I have read the abstract with much interest.

As to the general principles, it would seem to be an excellent statement. In the matter of the use of preliminary maps and the actual location from them, I feel compelled to dissent when they are applied to difficult work. For a difficult country, the scientific location is a calculated one.

For locating in a mountainous country, on steep slopes, perhaps descending from a summit with long stretches of a maximum grade, "re-projecting and re-running lines to get the best" would be unsatisfactory. If the line is through thick forest or dense underbrush, it would be still more so.

On such work the experience of the writer is in favor of:

First.—An accurate preliminary, as near the final line as possible.

Second.—Careful topographical notes, carried as far out as necessary.

Third.—A map carefully platted to a scale of 50 ft. to 1 in.

Fourth.—A final line fitted on the map and drawn in.

Fifth.—The final line to be calculated with reference to the preliminary, so that notes can be given the locating party to run in.

Such a location will rarely require any modification afterwards.

If the location is on a maximum grade with compensation for curvature, the preliminary should be run from the summit down, with the same maximum grade and with compensation for angles turned.

The writer does not advance these ideas as new ones, but simply as a part of the subject treated.

W. B. STOREY, Jr., M. Am. Soc. C. E. (by letter).—It may be of interest, in the discussion of Railroad Location, to note certain methods followed on the Pacific System of the Southern Pacific Company, under Mr. William Hood, Chief Engineer.

Examination of country and determination of routes for instrumental survey are similar to the methods usually followed, which are described by Mr. Lynch. The difference begins on the instrumental survey. The parties are organized as usual, except that the head chainman is the best-paid man in the party, outside of the instrument men, the rodman ranking next. Especial care is paid to chainage, both chainmen being required to use plumb bobs and both being supplied with hand levels for leveling chain. The chain is checked daily by a standard steel tape. The amount of error allowed is $\frac{2}{10}$ ft.

in 1 000 ft., or about 1 ft. per mile. This kind of work is done on all kinds of work, preliminary as well as location.

The transit work is given equal care. If running on a grade line, a line of check levels is carried ahead of the transit instead of behind, and the check leveler also runs a line of grade levels, getting his distances by pacing.

The preliminary is an angular line, run as near where the final location will be as it is possible for the engineer in charge of the field party to tell, using the line of grade levels and a compass as a guide. This requires an experienced locating engineer, and even then it is sometimes necessary to back up and try another way. On open country less backing up is necessary, provided always that the engineer has studied his country carefully before the line is run. The object aimed at is to have the preliminary as near as possible of the same length as the location and the same so far as angles are concerned, and to make it a working base for study of the ground with reference to location.

The notes of this carefully run preliminary line are platted on scales much larger than the usual practice, viz., from 50 ft. to 1 in. in mountain country, to 100 ft. to 1 in. where longer tangents are used, and in some cases to 400 ft. to 1 in. Extreme care is taken with this plat, the angles being laid off by means of tangent tables, the distances carefully checked and the stations with plus fifties pricked on. This plat is then turned over to the locating engineer, together with a profile of the line. No contour notes or other notes are placed on the plat, but simply the line.

Then comes another departure from usual methods. The engineer takes two men, with hand level, rod, chain and profile, and goes on the ground personally. He takes notes in the field of the data, which the engineer usually studies on the contour map. He notes also details, which in many cases seriously affect cost of work, but which are not shown on contour maps, for two reasons, viz., that the scale is too small, and that the man who took the contour notes did not know what should be taken. These notes taken by the locating engineer supply him with everything necessary to enable him to make a careful, close, final location. With his memory keeping in mind the entire country, he goes to work on his plat and determines the best place for the line. He draws his tangents and their connecting curves, or, as might be said in mountainous country, his curves and connecting tangents, about as is usually done, but with a much more intimate knowledge of his work than can possibly be obtained by usual methods.

Here comes another radical difference. The location is transferred from the paper to the ground, not by scaling, but by calculation. Each tangent is fixed, and the connecting curves are all calculated in the office by carrying the line from one fixed tangent around through

the preliminary line to the next tangent. These calculated notes are then given to a machine known as the locating party and put on the ground by it. Every half mile or so a check is given to be taken on the preliminary, and this check must come out within certain limits, or there is error either in the preliminary or location, and it must be looked up. A record of checks is kept and left in the office at night, and this affords means for the engineer to see how the men are doing their work, and to know that errors do not exist for the constructing engineer to pick up.

A trip over the line by the locating engineer completes the work. He then notes culverts and other necessary details and sees that everything is as planned.

Of course there are alternate lines to be run, and other matters connected with location are as usually done. The unique features of Mr. Hood's methods are the carefulness with which all the work is done, the system of checks by which error in the finished line is next to impossible, and the intimate knowledge of the work required of the locating engineer. The keynote of the thing is accuracy. It is probable that more miles of railroad have been located in this manner than by any other one system of location in the United States. The Sunset route from near Los Angeles, Cal., to the crossing of Devil's River, Texas, the line over the Tehachapi Mountains, in Southern California, and the line up the cañon of the Sacramento to Mount Shasta, thence over the Siskiyou Mountains into Oregon, are well-known examples.

There are, of course, many minor details connected with location that cannot be mentioned in a general paper. It will not be amiss, however, to mention one that I consider very important, and one that is neglected by nine-tenths of the locating engineers in this country, viz., the manner of staking the line. The rule with us is to use stakes about 18 ins. long, or longer in soft ground, and to drive them so that from 4 to 6 ins. remain out of the ground with from 12 to 14 ins. in the ground. It is too often the case that surveys costing thousands of dollars are worthless in a year or two after being made, and when the company is ready for construction the entire location has to be made over, because the locating engineer has not paid attention to the small matter of seeing that stakes were well driven.

Relative to reconnoissance, Mr. Lynch does not mention the use of the odometer. On our western deserts we substitute two good mules, a buckboard and an odometer for the horse spoken of by him, and obtain very close results.

In conclusion, I would say that the rules laid down by Mr. Lynch are seemingly expensive, and the methods described above even more so, but it will be found that they pay, and that by using them railroads can be built for much less money than by the old methods. I admit, however, that the item "location" will form a greater percentage of the total cost than formerly.

HOWARD G. KELLEY, M. Am. Soc. C. E. (by letter).—The paper presented by Mr. Lynch appears to me to be a step in the right direction, and is a practical description of the work of a branch of the profession which it is impossible to learn from text books.

In considering that portion of the article where Mr. Lynch says that the south and east slopes of valleys are more rugged and steep than the north and west slopes, the most notable example will be the great Continental Divide, with its long, gradual descent from the mountains to the Mississippi Valley on the east, and the sharp and rugged descent from the summit of the mountains to the Pacific Coast on the west.

The writer has also compared it with his own local experience in different parts of the country, and, while a corroboration is somewhat obscure in many localities, there are some examples where the theory appears to be borne out; but so far as it applies to local conditions, the writer would be inclined to consider it more as a condition liable to exist and to be expected than as a general law of universal application.

On the Columbia River, from Wallula Junction to the mouth of the Willamette River, in Oregon, the south bank of the river presented the rougher and more rugged country along which to locate a line; the south bank of the Puyallup River, in the State of Washington, is also rougher than the north bank, or, in other words, the river hugs the south side of the valley. In the case of other rivers of the Northwest, breaking, as they do, through mountain gorges, the examples are more obscure.

In the case of the St. Louis Southwestern Railway, at the points of crossing of the White, Arkansas and Red rivers in Arkansas, the conformation is obscure, as the rivers flow southeasterly: but the right-hand bank of all of these rivers is the more rugged in that particular vicinity. In Texas, however, the crossings of the Trinity and Brazos rivers show the steeper slope to be on the east bank.

The experience of our locating engineers will bear out Mr. Lynch that a thorough and careful reconnoissance is indispensable for a good location whether the country be new and unmapped or thickly inhabited. In the case of the unmapped countries of our western territories, the work of the engineer on reconnoissance is one of privation and hardships, requiring the strongest physique and powers of endurance; it has usually been done by an engineer attended by one or two assistants or "packers," the blankets and provisions being carried on the back by the aid of pack-straps, and many of the engineers of this Society can look back a few years to periods of semi-starvation and terrible exposure among our western mountain ranges. In such examinations nothing but experience and the natural faculty of location will enable the engineer to form a correct opinion as to the line to be used and the distance traveled.

In the West, the mule or "cayuse" pack-train takes the place of the team and wagon of the less rugged and more thickly settled country, the usual load for a pack animal varying from 250 to 350 lbs., depending upon the character of the trails, although the writer was at one time a member of a party which was relieved with provisions late in the spring after a long winter's siege, the animals in this case being barely able to travel through the snow with but 50 lbs. of load to the animal; but the luxury of a frozen can of tomatoes, split open with an axe, was more keenly enjoyed that day than a banquet at Delmonico's would be now.

The writer's personal preference is for a map drawn to a scale of 400 ft. to 1 in., as it corresponds with the scale of the profile paper; but for especially rugged sections a scale of 100 ft. to 1 in., with contours for every 5 ft. in vertical height, would be recommended.

A convenient way of taking accurate contours for very difficult sections is to allow the topographer a helper or tapeman; the topographer uses a hand level, and the helper a light cross-section rod and 50-ft. tape; the leveler, as he levels over the line ahead of the topographer, has his rodman mark on the back of each stake its height above the datum plane to the nearest foot. The topographer knows the height of his own eye above his heel to the nearest tenth, and thus standing at the center stake for a start he can rapidly level up or down the side hill, carrying his height of eye (which corresponds to an instrument height) mentally; the distance out to each vertical 5 ft. being recorded in his topography book in a manner similar to the fractional form of a cross-section book, the vertical height being the numerator, and the distance out from the center line the denominator. A skillful topographer can in this way keep up with the party, and the day's record is rapidly transferred to the contour map in camp at night.

It will be surprising to those who have not used this method what an accurate profile can be made from the contour map upon which a trial location has been projected.

The writer's later experience on maintenance corroborates Mr. Lynch, that a stretch of level grade is advisable between two descending grades; he has observed that the cars are less liable to bunch or break in two (that is, become uncoupled while running), where grades are adjusted as above, and further, that derailments are more frequent where two sharp descending grades come together, with nothing but a short vertical curve between them.

It is to be hoped that this very interesting paper presented by Mr. Lynch will receive a thorough discussion, and that our locating engineers from different sections of the country will add to the information presented by him.

D. H. Ainsworth, M. Am. Soc. C. E. (by letter).—Mr. Lynch is right in saying that "fixed or inflexible rules for location cannot be

laid down," but does he believe, even then, in leaving, sufficient discretion to the engineer?

We will take for granted that the engineer cannot know too much of his subject; that he has learned all about the physical obstacles to be encountered; all about the drainage and elevations; that he has employed a skillful topographer, and can make in his office a profile of any probable line; that he knows the population of each township, and the important trade points, and has availed himself of every means of obtaining information, not fearing to be accused of a want of reliance upon his own "eye for country."

Then does he know who is behind him with means, and how much per mile he can rely upon being spent, and how much he can prove can be made to afford a reasonable return on investment? In other words, has he any right to do anything that will not pay either directly or indirectly, immediately or in the near future?

May he not do worse than the best, with a certainty that finally his road may not have to be rebuilt?

Has he a right to consider his own reputation as an engineer the one thing paramount, assuming that he undertakes nobody's dirty work, and that he has decided all ethical questions properly and on the side of honor and right; that he is employed by no mere subsidy hunter or adventurer working merely for what can be made out of mere construction, and that his employers intend to operate as a commercial enterprise the project he is engaged in?

If he pleases, let it be his own money he is to use which gives him full control, would he do differently than if using the means of somebody else? I have in mind an instance where I myself proposed a tunnel cut-off that would now be deemed a good engineering feat, but that the company properly objected to spending their money in what they deemed an unremunerative project. Again, an engineer resigned because, notwithstanding his protest, the advice of the consulting engineer was taken, and an increased distance of 35% was injected into the line. While I have no doubt about the validity of the engineer's objections, I always claimed that he need not have resigned, as, after his protest, the responsibility was off his shoulders, and shifted to those of others.

I once located a line as I thought it ought to be built, but showed how it might be cheapened by a change at one point. I had nothing to do with the construction, but what I deemed the poorer line was used because of this saving of expense, to my own mortification, and I concluded never again to show what might be done unless it was what ought to have been done. Was this right? Is it right for an engineer to use deceit in any way because he knows what use will be made of the truth? For instance, he locates a line, but finds he can throw out several of his cheapest miles—of course, a saving of both cost and

distance—but increases the cost per mile, which will be considered in spite of him. Is he not justified in keeping his first location to himself? This is no mere speculation, but has been part of more than one engineer's experience. A man starts to do his best work, but a president, or possibly a chief engineer, gives him a value per mile of saving of distance. Invariably such valuation is not adhered to, and fault is found with the engineer, and changes ordered because he has taken some one else's advice.

Many a western engineer has had his work criticised because it was not done in accordance with views adopted twenty years later, when, if those views had been entertained at the time, the work would never have been undertaken, or would have been postponed indefinitely, those spending the money in improvements, or, possibly, re-building, being quite facetious at the expense of the original.

I have in view a short railroad that has been in operation twelve years and never paid, because handicapped by the expense of a bridge, the cost of which took all the profits of the other 35 or 40 miles. Still, the locating engineer got credit for finding a place for such a structure, which was proof of his ability, and possibly the engineer who had studied for its avoidance would always have the reputation of a nobody, even if he got something profitable for his employers.

How many engineers will admit that any railroad is either a fraud or failure that does not now nor never will pay a dividend; that one that cannot compete with ox or mule trains has no right to existence?

Again, secrecy as well as haste is frequently a good qualification for an engineer. A "booming" city cannot be approached safely with a publication "in town meeting" of a company's designs. A company has a right to a policy which a real-estate dealer may not know, and it sometimes calls for a good deal of policy on the part of the engineer to avoid publicity.

I have tried stadia work successfully in additions to St. Paul, simply to keep from real-estate agents the knowledge that a railroad was likely to need some of his wares, by having a party so small that it was not suspected of belonging to a railroad company, but rather to a city or local engineer's force.

The late Col. F. U. Farquhar once expressed surprise that railroad engineers did not make more use of stadia measurements, and I think I have profited by the hint.

Mr. Lynch, having been in the wilds of Texas, certainly knows of the necessity of always carrying along a duplicate set of instruments, to be available in case of accident. With a transit with vertical limb and stadia hairs a second party can be put in the field, perhaps by the use of teamsters or any other supernumeraries, and a grade can be tested and a line run, that can be plotted, to test the practicability of any single plane. A preliminary could thus be secured over the whole of Mr. Lynch's 250 miles that will cost little money.

Perhaps at least half the distance requires only geographical knowledge to be obtained from a map. A spring wagon and four can thus be made useful in obtaining an accurate preliminary knowledge of the whole 250 miles. Of course I would not leave out the two barometers that have to be used with so much care in accomplishing good guess work.

I would insist, also, on having a good topographer, no matter how much salary was required to secure one. They are scarcer than they ought to be; I mean such as can be trusted to get contours within 500 ft. of him with sufficient accuracy to make a good profile within those limits. My own experience has been to advertise for one, taking on trial each one that came, discharging as soon as incompetency was discovered, and securing a good one at any reasonable salary. My experience, too, has been against promotion, or trying to make something else of the man secured for this specific purpose.

C. D. PURDON, M. Am. Soc. C. E. (by letter).—A locating engineer is born, not made; without a natural aptitude for the work, a man is unlikely to be a successful locating engineer, study he never so much. Still, a discussion on the question is of value, for, although an engineer may have had large experience, the ideas of other engineers are of service, if they should only suggest a subject to think upon.

Many locating engineers do not seem to keep sufficiently in view the fact that a line has to be operated after it is constructed, and this may cause location, which, while seemingly economical, is, in reality, the reverse.

As a general rule, embankment is better to operate than excavation; still, it is common to see a line which follows a creek bottom carefully located so as to have the center line as nearly as possible at grade, and the cuttings just about sufficient to make the fills, giving a succession of short cuts and fills with a necessity for a bridge or culvert in each fill. A better location, from an operating point of view, would be to keep the line in the bottom on a moderate embankment, and collect the water to a fewer number of larger openings, reducing the number of bridges to be maintained and avoiding soft cuttings in rainy weather. The mere earthwork on a road is but a small part of the cost of construction, and it is poor policy to sacrifice grades and alignment to save a few hundred cubic yards per mile, especially to sacrifice alignment; for, while grades can be improved, it is a different matter to improve alignment, except within narrow limits.

Sharp curves also, while they may reduce the quantity of earthwork, limit speed of trains and materially increase the wear of rails and wheels, besides having other disadvantages.

The economy in construction only occurs once; the waste in operation is perpetual.

When a country is sectionized, the work of reconnaissance is much

assisted, as governing points can be easily located in advance by section corners. The information obtained from the average farmer, although his advice is always freely offered, is rather delusive; he generally has a pet "plumb level route" which he is anxious to show, and his ideas of high water-marks, with best possible intentions, are of a vague nature; a very common high water-mark is "deep enough to swim a horse."

I agree with Mr. Lynch as to its being a bad practice to survey without a camp outfit and sufficient teams; besides the discomfort, enough time is generally lost to purchase several camps.

Speaking of the topographer, Mr. R. L. Van Sant, M. Am. Soc. C. E., employs a neat method of taking topography. The topographer keeps a day behind the party, and has the previous line plotted upon a piece of tracing linen, with the elevations of the different contours marked where they cross the line. Taking this tracing, with a scrap of cross-section paper of suitable scale under it, the contours, streams, etc., are plotted in the field with considerable accuracy, and very rapidly transferred to the map by laying the tracing over it.

It is rarely the case that an engineer gets sufficient time to make a location, the company being in a hurry for profile; it might be broadly stated that no engineer has yet made a location where he did not observe points capable of improvement on going over the line after construction.

The average of about one mile per day in average country, of completed location, agrees closely with my own experience. I think the average cost of location might be taken at $60 per mile.

Preliminary lines should have the instrumental work and chaining very carefully done; and the map should be plotted by latitude and departure, retaining the calculated notes for use in projecting location and making field notes therefor. By doing so I have generally found that the located line came on the ground where it was projected, and many of the curves could be run directly without first running the tangents to intersection.

There is some difference of opinion as to the proper amount to reduce grades for curvature. I do not think it material whether the amount of reduction used be exactly correct; if it is excessive, an engine will stall on the tangent; if too little, on the curve.

Vertical curves in gradients should always be used. I have found Mr. Lynch's rule give good results, besides having the merit of being easily remembered.

As Mr. Lynch has had a very large experience in location, his remarks thereon deserve attention, and I know his methods to be thoroughly practical.

Mr. R. G. TARR (by letter).—Mr. Lynch states that a divide is not equidistant between two streams, but is nearer one of them, and that the slope on this side is steeper. This follows as a necessary result in

the vast majority of cases, because the intensity of erosion is greater; in other words, the stream has more work to do in a short distance. The reason why the divide is at a greater distance from one stream than from another is too complicated a subject for discussion here. It depends upon geological conditions, often of great complexity, and also at times upon variations in rainfall upon the two sides.

There are, however, exceptions to this general statement, as, for instance, when a stream has had its normal development interrupted by some accident. This is the case in some of the northern streams, north of the terminal moraine, that is, north of a line passing through Long Island, Central New Jersey, Northwestern Pennsylvania, and, in general, westward to Madison, Wis., and thence northwestward. North of this line many of the streams have accidental courses, caused by dams of drift placed across their courses by the continental glacier. This statement is therefore not an absolutely safe one to follow.

With reference to the other points made by Mr. Lynch in this connection, namely, that the slope is steeper on the south side of an east and west valley, and on the east side of a north and south valley, I am convinced that he is in error. No such generalization can be made, and the case of the Pacific slope, which he mentions, is dependent upon geological conditions, as indeed is the entire subject of the position of divides and the slope of valleys. It is a complicated subject, and no single law can be stated which will not be found to have innumerable exceptions; and many exceptions to the generalization which the author makes can be found easily. Where the attitude of the rocks is favorable, as, for instance, where they are tilted toward the east, the eastern side of a valley is usually steep and the western side gentle; but the reverse is equally true where the rocks dip in the opposite direction.

A knowledge of the geology of the country will often be of value, and the trained geologist can do reconnoissance work of this nature better than the engineer, which is one reason why I believe a railroad engineer's training should include not a little geology.

E. H. Beckler, M. Am. Soc. C. E. (by letter).—Mr. Lynch's paper treats principally of the "survey," with but slight reference to the principles of "railroad location."

I can hardly agree with him that general principles cannot be laid down by means of "fixed or inflexible rules," which should govern "location" in most all situations. Without rules, for instance, fixing a value upon distance, degree, rise and fall, radius and rate of gradient, by which comparison of alternate lines can be made, or by which a line can be adjusted to a proper expenditure for grading, the locating engineer would be groping in the dark.

On a line of road where several locating engineers were employed

there would be as many different ideas as there were individuals, and the chief engineer would find that some of his men were locating a road suitable for a trunk-line business, while others would be setting stakes for a branch road, with tri-weekly trains. There must be rules for guidance in order to produce a harmonious result.

The locating engineer should have an approximate idea of the cost of all the elements which enter into the completed roadbed, such as prices for grading, bridging, masonry, etc. In fact, he should make an estimate of the cost of each mile of road as fast as located, placing the quantities upon the profile. In this way attention will sometimes be called to unusual or expensive work, which might otherwise escape notice for the time being.

The outfit used by Mr. Lynch for reconnaissance I have found to be sufficient. The mode of transportation should be varied according to needs.

By reconnaissance made between Fort Assinaboine, Mont., and Spokane, Wash., the distance was estimated to be 518 miles. When measured, it proved to be 512 miles. Certain intermediate points were more than 10 miles off. The route was examined by four men, on different sections, with transportation by buckboard, horseback or afoot, with pack on the back, in dense forest, where five miles a day was good progress.

The manner of conducting surveys differs materially according to the character of the country. Camp equipment, kind of supplies for subsistence, mode of transportation and number of men in the party vary as the physical features and nature of the work demand.

Profiles should be made in duplicate, and the map, made on manilla paper, should be traced in the field office. Office work should be kept up with progress of field work. Maps and profiles should be in sections of about 20 miles, and forwarded to the chief engineer with all notes as fast as completed. The scales of maps proposed by Mr. Lynch I have found to be most convenient.

The daily progress of a party is a variable quantity; 1 000 ft. in some places are attended with more work than 10 miles in other localities. The only correct location for any country, requiring cuts and fills, is one made by an engineer in the field. The office projection is a help to more quickly reach the result.

I have found that equating grade at the rate of 0.04 per degree for curvature was not sufficient where the maximum grade was less than 1 per cent.

On grades of 2% or steeper there seems to be little need of transition curves. It is more convenient to have the easement curve run in, when retracing the line, as such work delays the location party. I would provide tangent room between reversing curves for this purpose. The tangent should not be less than 20 times the sum of the rates

(degrees) of the two curves. When this would make a tangent less than 200 ft., the rule should be discarded and that limit used. On cheap branch lines this tangent can be reduced to 100 ft.

I am afraid that the example cited by Mr. Lynch for a vertical curve on a summit would give a curve very much too short for such a situation. This rule will work very well where there is not too great a change in gradient. There are frequently natural obstacles which cannot be removed, controlling the curvature and gradient. The amount to be expended in changing the face of Nature depends largely upon the proposed traffic.

Mr. HENRY GANNETT * (by letter).—I have read with much interest the abstract of Mr. Lynch's paper upon "Railroad Location." What I have to say in the way of discussion is suggested by the last paragraph, which is as follows:

"It is quite apparent that methods such as have been described are inapplicable to countries where topographical surveys already exist, upon which the location can be intelligently projected and the line approximately laid out in the office. This system applies more for countries like America, Russia and others of large extent, where large areas are yet uncovered by topographical surveys."

The advantages of such topographical maps to the location engineer are apparent. They obviate the necessity of making any preliminary reconnoissances, since from them all feasible routes which are worthy of being examined in greater detail can be selected at once. Not only this, but in most cases an examination of a map reduces the routes which it seems worth while to examine more closely to one, two or three, and thus obviates the necessity of running many trial lines. Moreover, when a route has been thus selected, the engineer has the fullest possible assurance that he has the best route which the country affords. It is impossible that further exploration of the country can develop any better route than that already selected. With so many cases before us of badly located roads, roads which have been located badly because of an insufficient knowledge of the country, roads which have been shifted and straightened after completion, because a more intimate knowledge of the ground has shown that better routes existed, it seems strange that different methods of making preliminary reconnoissances have not been adopted.

Now, what I wish to advocate is the substitution for this preliminary reconnoissance work, which is treated of in this paper, the making of a topographic map. Such a map should embrace a belt of country between the points which the railroad must touch, of a width sufficiently great to include within it all possible routes. For instance, in the case which Mr. Lynch cites of a road between terminal points 250 miles apart, touching in its course several intervening towns, it is

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probable that a map of a strip of country 25 miles in width will cover all possible routes. Such a map of an area of 6 250 sq. miles, which will answer the requirements of preliminary railroad location, can be made at a cost ranging from $60 000 in the eastern part of the country down to $10 000 or $15 000 in the Mississippi Valley and on the plains, and up to perhaps double that amount in the Rocky Mountain region. I do not know what relation this expense would bear to that usually incurred for reconnoissance surveys, which it is designed to supplant; but I think I am safe in saying that the latter would cost several times this amount, besides, as has been shown above, meeting the requirements in several respects very inadequately. I therefore suggest for the consideration of engineers engaged in railroad location the advisability of making this radical change in methods.

J. Q. BARLOW, M. Am. Soc. C. E. (by letter).—I believe the points in Mr. Lynch's paper are generally well taken.

After an experience embracing many thousand miles of reconnoissance and surveys in the Rocky Mountain and Pacific Coast regions, the writer believes the correct balance of all the conditions involved is often the hardest of attainment in what, at first sight, appears to be a region of no special difficulty. Where the position and direction of the drainage is favorable between objective points, but little difficulty is experienced in deciding upon the route. In rugged and mountainous regions involving carrying the line across one or more summits, the problem is one of more difficulty, but a thorough reconnoissance generally brings out the distinctive advantage of some particular line as one of unquestioned superiority.

But most experienced engineers have at some time or other been confronted with a wide area of country over which it was necessary to locate a line, and while in no sense mountainous or even rugged in appearance, yet upon detailed examination proved to be full of gulches and swales, somewhat rolling and having no well-defined system of drainage in any given direction as a whole, and somewhat similar, probably, to what Mr. Wellington in his book describes as "a country worse than it looks." It is such a country as this which may, at a distance, have the innocent appearance of a gently rolling plain, but which, upon closer examination, often tries the patience, wits and muscular endurance of the engineer, in order to formulate satisfactorily unto himself the best plan of location across a region apparently all warped out of shape.

The writer has often noticed the point brought out by Mr. Lynch with regard to the north slope of east and west valleys and gulches being much less rugged, and has always thought it to be due to the fact of greater exposure to the sun in winter and consequent freezing and thawing, which for ages have operated to disintegrate, wash down and smooth over to some extent their former roughness; and this

fact often cuts a considerable figure in carrying a supported line off from a summit, as well as more freedom from snow in operation.

Mr. Lynch recommends an 800-ft. scale for preliminary maps, and in difficult sections a 400-ft. scale. In all grade line and contour projection work this is entirely too small; in difficult mountain and cañon work 100 ft. to 1 in., with 10-ft. contours, gives best results. On all but the most difficult work a 200-ft. scale gives satisfaction and admits of projecting with such accuracy that a very good profile may be made from the map and but few corrections will have to be made in the field when the line is run in on the ground.

No standard can be set as to the amount of work accomplished in any given time by a field party. A party under the direction of the writer, while crossing a portion of the Great American Desert, in Western Utah, where no water exists for a distance of about 100 miles, nearly exhausted the water supply carried when about 70 of the 100 miles had been run. The following morning at 5 o'clock a start was made with a view to running 30 miles by dark and reach water. By quarter of two o'clock 20 miles had been run, including the levels, being 8 hours and 45 minutes of actual time, which includes about 15 minutes for lunch, and is, the writer believes, the best record for the time, and perhaps for a day, ever made. Owing to the teams giving out at this juncture, further progress was for the day abandoned.

The levelman used two rodmen, and a 200-ft. chain was used; but the most extraordinary part of the performance is perhaps the speed of the leveler, but it is accounted for by a clear atmosphere, very level country, and rapid manipulation. It might further be mentioned as a matter of interest, that this work was a portion of a circuit of about 1 700 miles of levels which closed within 7 ft.

There is a wide difference from this extreme to that of difficult mountain work, where sometimes for weeks together an average per day of less than ¼ mile is accomplished; and in one instance, where one of the writer's parties was nearly six weeks in locating 1½ miles of extremely difficult cañon work, including the same length of preliminary line, much of the ground on which the line was located being inaccessible, except for a bird, a large amount of complicated triangulation was necessary, and often from the opposite side of the cañon.

It cannot be denied that there are many examples of poor location to be met with, which are hard to justify under any conditions; but on the other hand, we sometimes hear harsh and unjust criticism on the location of lines, considering only the conditions they are being required to fulfill at present, and with no regard for the conditions as they existed in fact and prospective at the time the line was laid out.

Then, the balance of business may have been eastward; now, it may be westward ; then, five trains daily may have seemed a large estimate ;

now, 25 trains may be run daily; then, the young company may have been struggling and poor, and the fact may to-day be reflected in its location, and rather than being proper subject for criticism, it is perhaps the wonder that the earlier railway locators builded as well as they did.

Mr. W. M. Davis* (by letter).—Mr. Lynch's statement regarding the position of steeper slopes in valleys seems to me open to numberless exceptions, and therefore of problematical value in so important a matter as railroad location. The factors on which steepness of valley slopes chiefly depend are, the structure of the region traversed by the stream; the age of the valley (that is, the stage of its geographical development); the meandering of the stream; and, in a subordinate way, the action of sunshine on the slopes; the action of wind; the presumed influence of the earth's rotation. These several controls may be briefly considered.

The structure of the region is all-important. Horizontal strata allow the development of symmetrical slopes on either side of the stream; but if the stream meanders, the slope on the outer side of its curves is the steeper, as is well known. The gorge of the north branch of the Susquehanna in Pennsylvania, the valley of the Osage in Missouri, and many others, might be mentioned in illustration of this fact. Where the river course is comparatively straight, the valley slopes are relatively symmetrical; but where the river course is tortuous, the banks are often extremely unsymmetrical; and the steeper slope is then on the outside of the curve, whether this be east or west, north or south.

Tilted stratified structures nearly always determine an unsymmetrical form of valley section; but no definite rule can be given for the steeper and gentler slopes, as they depend on variable factors, such as thickness and resistance of the several strata concerned. In monoclinal structures of moderate dip, it is, however, most commonly the case that the steeper slope is on the side of the descent of the strata. This is illustrated over and over again in the Appalachian belt.

Massive crystalline rocks are so complicated in structure that no simple statement can be made concerning the form of valleys carved in them.

The age of the valley is also a matter of great importance. Young valleys are always steep-sided; for example, the gorge of the Niagara or the cañon of the Colorado, their depth depending more on the altitude of the country than on their age. Adolescent valleys have gentler slopes, as along the Ohio. The Connecticut valley is older, and has generally wide, open meadows, as by Hartford; but where the rocks along its path are hard, the slopes are still steep, as below Middletown.

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The effect of a meandering course has been mentioned above. This effect is locally strong enough to form exceptions to the rules based on the other kinds of controls. Illustrations of it may be cited in great number.

The smaller controls—sunshine, winds, and the earth's rotation—are comparatively problematical. I believe that engineers find that the sunny slope of a railroad cut is the more readily attacked by the forces by which rocks are decomposed, presumably because of the greater number of strong temperature variations to which it is exposed. The same principle might apply in forming large valley slopes, provided other controls were indifferent. If sunshine were the determining cause, a slope to the south-southwest (in our temperate zone) might be more generally of moderate declivity than one in the opposite direction; but I think it must be rare that this control acts alone, or as a determining cause of form.

The action of the wind may be mentioned; but it is probably negligible in small streams, and other controls may overcome it, even in large rivers.

The effect of the earth's rotation has been much discussed, and both sides are ably argued. It should be noticed that this effect, if apparent at all, should be seen on the right bank of rivers in this hemisphere, and on the left bank in the southern hemisphere, while its intensity should increase with the sine of the latitude. The statement ordinarily met with, that the deflective effect of the earth's rotation appears only in the meridional component of a river's motion, is incorrect. The deflective force is independent of the azimuth. A river running east or west is deflected just as much as a river of the same volume and velocity, in the same latitude, running north or south.

But, at most, this action must be small. Other controls must generally exceed it, for it is by no means a general rule that the right slope of our valleys is steeper than the left slope.

The valleys of certain streams in North Carolina and in Long Island have been instanced as exhibiting a form that might be ascribed to this control, as no other control is there apparent for their unsymmetrical form. The best examples of the kind that I know of are along the radial streams of southwestern France, excellently shown on the Army Staff map of that country (1 : 80 000); the streams run in nearly all courses between east-northeast and west-northwest, and nearly every stream has a steep slope from the hills on its right.

Now, Mr. Lynch states that "where a stream flows north or south, the east slope of the valley is invariably steeper, rougher and more broken than the west slope," and "where a stream flows east or west, the south slope of the valley is generally steeper, rougher and more broken than the north slope." It is manifest that if these statements are correct, there must be some predominant control of valley form

besides those generally recognized and mentioned above; and this conclusion is so unlikely that I am constrained to question the general applicability of Mr. Lynch's theorems. It can hardly be maintained that the rule of steeper slopes on the east, in north and south valleys, is "invariable;" the Hudson at New York City and for some miles above is a contradiction to that rule; but it accords with the rule of structure, for it follows the strike of a monocline structure, whose dip is westward, and its steeper slope is therefore on the Palisade shore. Many other exceptions to the rule might be named.

As to the confirmation of the rule by the continental example of North America, it seems to me very hazardous to introduce forms so unlike in dimension as valley slopes and continental slopes, as if they belonged in the same category. It is, of course, well known that both North and South America have the greater mountain ranges near their western coasts; but Australia has its mountains near the eastern coast. I hope that in the fuller publication of Mr. Lynch's paper, he will indicate by specific statement, the observations on which his rules of valley form are based.

It seems to me that if the engineer is to take advantage of the form of valleys in locating railroads—as he certainly ought to—he must be guided, not by empirical rules, to which many exceptions will be found, but by a practical knowledge of physical geography and physical geology. There is no other subject of study that so greatly increases the power of rapid perception of topographic features; and as Mr. Lynch's paper indicates, that power is of extreme importance to an engineer at work on new railroad locations.

KENNETH ALLEN, M. Am. Soc. C. E. (by letter).—There has been some discussion of late years as to the merits of the stadia for preliminary surveys. I think that depends entirely on what is required of the survey and on the character of the country traversed; but where the latter is open, and the feasibility of a project, the ruling grades and an approximate location of the best route are acquired, I think the stadia method will be found of greatest value. The saving in time and expense will be found very considerable and the above information with as minute detail of topography as is wished may be obtained, the latter work being extended *ad libitum* according to the ground covered. In other words, a much larger fund of general information may be obtained for the same money than by the usual method.

A survey of this kind properly belongs in an intermediate place between the reconnaissance and the chained preliminary survey, and under certain conditions it may prove an economical substitute for both. The economy, of course, results from the absence of chaining and stake driving and the consequent reduction in the size of the party. The line, however, should be so established by referencing turning points or angles that it can be recovered readily.

I do not consider the error in distance or level to be so much greater by this method (if, indeed, it is greater in the long run) as to be a serious objection to it. And although it may be easier to err in reading the stadia rod than to drop a station in chaining, the transitman will probably guard as much against the former as the chainman against the latter.

Having had an opportunity some six years ago to test this method of making a preliminary survey where the object sought was: 1, to ascertain the feasibility of constructing the road; 2, to establish the best general route, with distance, elevations and ruling grades; and 3, to furnish an approximate estimate of the cost of construction, I adopted it, and the following notes with reference thereto may be of interest:

The line ran almost entirely over a prairie country in Kansas and Nebraska, considerable of it cutting "across country" and requiring numerous trial lines to be run for comparison.

The established line was 312.13 miles in length, and the time taken for one party * for the entire field work was 5.7 months; or 2.1 miles of line were established per day with a party of transit-man, leveler, two rodmen, axeman and teamster. Deducting rainy days and time consumed in moving, the progress would probably have been about three miles per day.† The cost for the entire field work for salaries and expenses, but not including instruments, camp outfit and office work, averaged $11.03 per mile.

The work consisted in running bench levels, the projected line by stadia, including elevations of all controlling points on or near the line with vertical arc, referencing turning points and locating township and county lines. In addition, 23 miles of alternate line were run and a very considerable extent of territory reconnoitered on horseback.

The saving arising from the use of the stadia on this survey was probably at least 25 per cent.

Where one is familiar with the territory beforehand, where good contour maps of it exist, or, in other words, where the final location will necessarily be confined between comparatively narrow limits, and also in a wooded country—and these conditions obtain in a large number of cases—I am inclined to favor the ordinary method with transit and chain. Mr. T. G. Gribble, however, has employed the stadia with success, as he claims, not only for such preliminary work, but in the actual location, including the staking out of curves, of 70 miles of railway in Hawaii. For this, however, he employed a special instrument, magnifying 40 diameters instead of 25 or 28, as customary.

On a preliminary survey for a conduit route made about eight years

*Two parties were in the field a part of the time, but such time is counted double.

† Eight miles were run on one day. An axeman was not required on the entire survey.

ago for the city of Philadelphia by Rudolph Hering, M. Am. Soc. C. E., the following method was used with satisfactory results, the alignment and level checks indicating accurate results.

Bench levels were run near the projected line with double turning points. They were run in this way in order to avoid duplicating the work for a check, although a check was obtained subsequently by the completion of a circuit.

The transit party followed, driving stakes at turning points and at stations 200 ft. apart. Two transits were used, occupying alternate turning points, sighting to each other, turning vernier angles and checking with the needle. Elevations were carried by both transitmen with the vertical arc, checking on level benches. At each point occupied topography was taken with stadia and level rod for some distance each side of the line, depending on the ground, and continued by the rodmen by use of an Abney level or Linton's clinometer.

The results were platted on a scale of 800 ft. to 1 in. with 5-ft. contours, and on this plan the final location was projected.

The data as to cost and rate of progress I am unable to give, but my impression is that the latter was something over one mile per day on average ground, and that the party consisted of two transitmen, one leveler, three or four rodmen and one axeman.

With regard to such surveys, I would suggest the following: Run a line of bench levels ahead of the transit party, establish bench marks every half mile or so for the transit party to check on. Select a transit of good magnifying power and a stadia rod carrying a distinct graduation. Black and white has been found far preferable to other combinations for the entire graduation. Start on the true azimuth and turn angles on the true azimuth at each set-up, always reading the needle as a check. In more rapid and less precise work the needle alone may be used and alternate turning points only occupied by the instrument. On extended surveys check the bearings by an occasional observation for the meridian. Observe the position and elevation of all points controlling the location. Carry elevations through by the vertical arc.

Do not delay the work by attempting to keep the traverse coincident with the final center line where obstacles occur, as this line can be projected on the map and scaled or calculated, and will, moreover, as often as not, vary from the line as finally established.

Foster Crowell, M. Am. Soc. C. E. (by letter).—This paper, as its author intimates, aims to be suggestive rather than instructive; it opens a very wide field for discussion without much specific reference. Nevertheless, it may prove very useful by bringing out and emphasizing the undeveloped condition of the art of railway location, which is a marked and surprising feature in the greatest country of railroad builders in the world. If we compare the field methods of to-day with those of 40

years ago we will find there has been very little advance in the art, however much theory may have become enlightened, and despite the fact that in other surveying fields, such as park-making and suburban street development, for example, there have been marked improvements in instruments, methods and results. This is, doubtless, not entirely the fault of the profession; part of it is due to the ignorance and false economy of employers. There are, of course, some exceptions to this general statement; the aneroid stadia, plane table, and the camera have, sometimes, perhaps, and to a small extent, been employed for railroad surveys, and sometimes sufficient time is taken to thoroughly study the country before beginning the location. But, nevertheless, it is true, as a rule, so far as I have had opportunity to observe, that the old way is adhered to, of first of all putting a party into the field with a chain and transit, followed, instead of preceded, by a level, and blundering along as nearly as possible in the desired direction on a line that is considered to be tentative, but yet is expected to conform closely and to be a basis for the location to follow. The programme of preliminary, preliminary location, and final location, is in view, in a more or less complete form, but, as usually practiced, the first is commonly determinative of the last, and the test of a good locating engineer in the minds of laymen is as to how close he can adhere to it, or, in other words, how narrow can be the belt of examination. It is not to be denied that excellent results are often thus obtained by skilled engineers; but, on the other hand, this method does not, in any case, demonstrate that the best result has been attained.

Another test that is often applied of the proficiency of a locating engineer is his linear progress per day, a party who can cover two miles per day in a moderately difficult country being perhaps considered a hustler, while the party who makes but half a mile per day is voted slow; whereas, the results of the careful progress may save in the construction account many times the extra cost of the survey, for it requires but a small percentage of distance saved to meet the latter, not to speak of other obvious advantages to be gained. And such locations are naturally and usually very defective, especially in the details, some of which, such as "broken-backs" and reversions, Mr. Lynch has mentioned. The evils of "crowding the engineer" in the field are not overstated by Mr. Lynch. It frequently happens, too, that branches or extensions reflect and repeat errors with which the management may be already familiar on the present line, and the standard is, therefore, seldom ideal. Perhaps this accounts, in part, for the impression that appears to prevail in many high quarters that location is a comparatively unimportant thing and easy of accomplishment at sight.

Sometimes engineers are sent into the field with imperative limita-

tions (which are apt, in such cases, to be far too high) of grade and curvature, and instead of considering them as limitations, and only to be resorted to when unavoidable, they sail serenely along, using the maximum all along *ad libitum*, often to save light graduation costing less per linear foot than the extra length of track, and throttling the traffic capacity of the future road to a still more injurious extent. For all of these obvious reasons all the preliminary topographical information that can be obtained and utilized prior to the beginning of the line survey, within common-sense limits as to width of territory to be examined, should be fully studied and detail surveys and studies with stadia, camera and other labor-saving devices, should be made of such localities as present obvious alternative locations and the more difficult ground. This course will, in most cases, cost less, and generally be far more valuable than a complete continuing preliminary line survey, even if it does not further admit of a final location being made from it without preliminary location. There are, also, obvious advantages from the right-of-way point of view, in knowing the location before running on the actual line, and the cost and delay of revising the tentative line at difficult points is largely avoided.

Mr. Lynch's remark that railroads cannot properly be definitely located from a preliminary map in the office, and that the best results must be actually executed on the ground, is true, but only in a measure. It all depends on the preliminary map, and the method of its production; he probably wishes us to read between the lines. Branches of trunk lines may, sometimes, it is true, be located in an arbitrary and ill-considered manner from the general office.

I return for a moment to the author's observations of the greater steepness and roughness of the south slopes and the east slopes of valleys in this country. I do not know that I quite understand whether he refers to the declivity of the valley itself or of its cross-section; if he means the latter, I cannot say that my recollections bear out the statement sufficiently to make it general; not only are there marked departures from the rule in the case of separate streams, but the conditions vary in the same streams, the steepness being sometimes on one side and sometimes on the other. Whether true or not, it has not much bearing on location problems, however interesting geologically or geographically.

Altogether, I think the profession is indebted to Mr. Lynch for the suggestions in his paper, and, although, to some, they may be more or less self-evident, still, in view of the way they are generally disregarded in actual practice, they should be welcomed.

CHARLES H. SNOW, Assoc. M. Am. Soc. C. E. (by letter).—I have repeatedly been engaged in exploration work in the wilder portions of this continent, where horses could in no part of the work be used. In such instances, if parties are to be detached from sources of supply

for considerable intervals, the selection, as well as the transportation, of provision, shelter and instruments, will require the most careful consideration. This is a subject which has frequently not received the attention which it deserves, yet the character and quantity of work accomplished is directly affected by it. I have met more than one engineer who has been the victim of the ignorance or carelessness of others, even to incipient scurvy.

In my own experience, when all were upon short allowance and no supplies within five days' march, I had once to abandon provision which was perfectly good, but too bulky and heavy to get across an extended wooded swamp.

Food should be selected with regard to climate and the habits of the men employed. It should be nutritious, in variety, easily and quickly cooked, and compact. Canned vegetables and fruits are to be avoided as containing too much water, and, therefore, heavier, while no better than the same in desiccated state. Supplies are generally packed in small canvas bags, which are baled by wrapping them in the blankets, tents, etc.

Pack-straps, easily adjusted to any package and shoulder, are everywhere procurable. Packmen should hardly be loaded with more than 50 or 60 lbs. each, although I have known exceptional men to handle over 100 lbs. in rough country and for prolonged distances.

Extra compasses should always be carried. Long wire nails for improvising rafts for unexpected lakes are frequently invaluable. In explorations, as in other kinds of work, better results can sometimes be obtained in winter than in summer. Swamps are then frozen, and dog teams can frequently be employed, even in thick brush or over wind-falls. Toboggans drawn by dogs were used on parts of the Duluth, South Shore and Atlantic Railroad during early construction, the partially cleared location transit line furnishing fair going for the dogs. Topographical work can be done in wooded country as well in the winter as the summer, as the vegetation forms a satisfactory guide to the character of the ground. In warm climates, as on the Mexican table lands, outdoor work is to many more agreeable during the rainy season than in the hot dusts of the dryer portion of the year.

Foot-gear is another direct factor in the comfort and health of men upon the march. This is a point of sufficient importance to have received attention from the German and perhaps from other governments. Where in ignorance of conditions to be met, a serious mistake can hardly be made in selecting a shoe or boot pack. This, as known, is a sort of moccasin with heavy sole. It is manufactured throughout the east and west. For winter work, in cold latitudes, a thick felt stocking, belted above the knee with light rubber sandal, is widely used. In temperature as low as — 40° Fahr., and in deep snow, I have found this arrangement to be warm, comfortable and dry. Rubber boots are very unsatisfactory in all work of this description.

In reconnaissance through dense forests, the position of the party may be kept by a leader furnished with a large hand compass, with needle not sensitive, but which will quickly come to rest. The chief, particularly if unacquainted with the diverting hardships in unsettled districts, should not attempt to do this work. After a little practice the results obtained in getting round swamps, in making detours to cross rivers and yet come back again to the line of travel, is quite as surprising as the measurements determined by timing well-gaited horses, as mentioned by Mr. Lynch. Courses and distances are kept by the leader with his compass and by pacing. It is easily possible to travel two or three days away from camp in brush so thick as to obscure objects 100 ft. distant and over country without the slightest individuality, and returning another way, to strike camp closely. The quality of location work might sometimes be improved, if the construction engineers were placed upon the ground sufficiently early to study their separate divisions from a location standpoint. Sometimes slight improvements, in no wise involving the general system of location, can be introduced at large saving.

J. E. GREINER, M. Am. Soc. C. E. (by letter).—The author has paid little attention to one feature in location which, though probably of minor importance compared with the proper selection of route, grades and curves, still forms a part of the location of every railroad. I refer to the choice of bridge sites and the selection of the proper design for any particular opening.

Bridging of small streams is not usually done in the best and most economical manner. Spans are made too short and water-way is blocked, made too low and damaged by freshets, made too long and money wasted. Each locating engineer considers himself perfectly competent to fix upon the length of span and style of structure required for any particular stream upon a casual inspection of the crossing, although it has been demonstrated over and over again that the selection of a bridge, even for the most innocent-looking stream, requires careful judgment, based upon an accurate knowledge of the nature of the stream, its water-shed, its liability to a sudden rise and the height of freshets. A poor selection is sure to be exposed, sooner or later, to the maintenance officials after the road is in operation, while the locating engineer may be making the same selection elsewhere in total ignorance of previous poor judgment.

There are a few recommendations, mostly of a negative character, which may be worth considering in this connection.

First.—Limit the skew to 45°. For single crossing it is better to avoid skews. The stream, of course, can be crossed at any angle, but make abutments square with the axis of the bridge, or as near square as circumstances will permit, and the saving in masonry will frequently balance the increased cost of a square bridge with longer span. Bridges

with sharp skews cannot always be braced in a satisfactory and thoroughly efficient manner; besides this, the load coming upon one truss before it reaches the other is apt to cause racking or distortion to a more or less injurious degree.

Second.—Avoid sharp or broken-back curves. Bridges with curved alignments cost more, are more difficult to maintain and show the effects of wear in a shorter time than when straight. Knowing this, some engineers make a short tangent over the bridge, the P. C. being very near each abutment. This arrangement is just as hard on the bridge as is a curve, because the train has to recover from the effects of the centrifugal force caused by the curve at one approach, and then, almost before equilibrium is restored, prepare itself for the curve at the other approach. All this disturbed equilibrium takes place on the bridge and is not always considered in the design. The data furnished stating merely that alignment is straight, the designer, unless a bridge engineer in the employ of the railroad, does not go back of this information, and designs the bridge accordingly. The result is a weakness which soon makes itself felt.

Third.—Avoid half-through girders for small spans. The relative cost of deck and through-plate girders designed for 125-ton engines, erected ready for the rails, is given approximately in the following table, as is also the least distance from base of rail to under clearance:

Span.	Deck.			Through.		
	B. of R. to under clearance.		Cost.	B. of R. to under clearance.		Cost.
Feet.	Feet.	Inches.		Feet.	Inches.	
30.....	3	3	$525 00	2	3	$975 00
40.....	4	1	800 00	2	3	1 400 00
50.....	5	0	1 160 00	2	3	1 910 00
60.....	5	11	1 610 00	2	3	2 510 00
70.....	6	8	2 120 00	2	4	3 170 00
80.....	7	6	2 700 00	2	4	3 900 00
90.....	8	4	3 375 00	2	6	4 725 00
100.....	9	2	4 125 00	2	6	5 625 00

An examination of the above table will show that through-plate girders cost from 36 to 85% more than deck; that for the same money a deck girder can be built about 17 ft. longer than a through; that with 12 ft. depth of water a deck bridge costing the same as a through bridge can be made to have the same clearance as through girders up to 50-ft. spans, and with 20 ft. depth of water up to 70-ft. spans.

There is, of course, no objection to the use of through-plate girders when circumstances so demand, but the deck girders giving a roadway clear of all obstructions should always have the preference.

Single-track through-plate girders over 8 ft. deep, having a very shallow floor, as, for instance, when cross-ties rest directly on bottom

flanges, are abortions. The cross-struts and knee braces do not stiffen the top flanges nor hold them in line; when a train crosses, the girders cant inward and convey the idea that they are going to upset. The rushing of trains over such structures makes a thundering noise very objectionable when heard unawares or at night.

Fourth.—Avoid using three trusses or girders in double-track structures. There are cases when such a design will save material, and consequently cost less than by using two or four trusses or girders, but an examination into the action of such structures in actual service has convinced the writer that they are fallacious in spite of all care taken to proportion the trusses and bracing for existing conditions. The trusses will not work together except when both tracks are loaded. When the train is on one track only, the unequal deflection will distort the bridge and loosen rivets in struts and floor beams, while in deck trusses the sway frames cannot be kept in adjustment, or when made of shape iron and riveted, the rivets pull loose. In cases of adjustable sway rods, the continual tinkering to which they are subjected will eventually so distort the cross-section as to cause the bars in the various panels to take unequal strain. The writer knows of a bridge of this description having three-deck trusses resting on artificial stone pedestals. The bed-plates in the outer trusses have worked into the stone about 1 in. during a period of about nine years, while the bearings under the center truss have not worn more than $\frac{1}{4}$ in. The distortion in the case therefore is about $\frac{7}{8}$ in., and something had to give this amount. The cause is evidently due to the unequal straining of the outer and center trusses when one track is loaded, the outer truss taking its full load, while the center gets but one-half its load; consequently, as two trains seldom meet on the bridge, outer trusses do about twice the work done by the center truss, and the soft-stone bearing under the outer trusses will naturally wear much faster than the center bearings.

Attempts have been made to formulate rules for the most economical layout of spans over a wide stream or river.

One author states that this is effected when the cost of trusses and lateral system about equals the cost of the substructure, and gives a mathematical proof of the statement. Whether true or not, such a rule is of no practical value. A rule cannot be made to fit all cases, and the best plan therefore is to find the best layout by trial estimates. That these estimates should be made by the bridge and not the locating engineer goes without saying, or if the company has no bridge engineer, they had better submit a cross-section of the stream showing the nature of soil and the established grades to a reliable bridge company and allow it to determine the layout.

JAMES R. MAXWELL, M. Am. Soc. C. E. (by letter).—The paper of Mr. Lynch is admirable. As he says, "no fixed or inflexible rules for location can be laid down." Each case presents some new problems that

must be solved on the ground. The maps of the States and territories where the land has been subdivided by the Government are more accurate than those in the other States. With these maps and a good aneroid barometer, a very good reconnoissance can be made, and the position of the line and the maximum grades closely determined, if the weather is settled. It is better to have an assistant, and two or more barometers along, so that in unsettled weather one observer can be left at a controlling point, either the summit or the valley, to note all changes and the time of their occurrence; the other, to go ahead and take his reading and the time; then return and check up, and if there is any material difference, to repeat the readings, but exchanging the barometers. This causes much work and delay, but it pays to make sure.

My experience in the States of Washington, Nevada and California agrees in general with what Mr. Lynch says about the steepest slopes and the roughest ground being found on the west or south side of the ranges. A very marked instance of this was found in the southern part of California, in crossing the Sierra Nevada. On the east side, light work, with 1% grade, and but little curvature was encountered; while on the west side, there was very heavy work, a large amount of maximum curvature and 2% grades. In the southern part of Pennsylvania, the light grades are found on the western slope of the Alleghenies. The locating party should always be provided with a team to carry them to and from work, and, if the survey is of any magnitude, with a full camp outfit also.

As Mr. Lynch says truly: "There is no royal road to railroad location; it must be executed on the ground," and permit me to add that it should never be considered finished until the grading has so far advanced that any more changes are impracticable.

Harvey Linton, M. Am. Soc. C. E. (by letter).—A piedometer adjusted to show correctly the distance traversed is a useful addition to the instruments carried in a reconnoissance.

As the location of a railroad in countries where topographical surveys exist may be satisfactorily determined in the office, it seems reasonable that some of the methods used in making these topographical surveys may be applied with advantage in preliminary surveys for railroad location, particularly in open and rolling country.

The methods of stadia surveying for a railroad line may vary in details from those used in filling in large areas of topography. In such a survey each station or turning point on the line should be occupied by a theodolite or a transit instrument (the transit feature of the instrument is not required), so that the azimuth angles may be measured.

If there are two instruments and two surveyors, the distance and the difference in elevation, or the vertical angle between any two sta-

PLATE VIII.
TRANS. AM. SOC. CIV. ENGRS.
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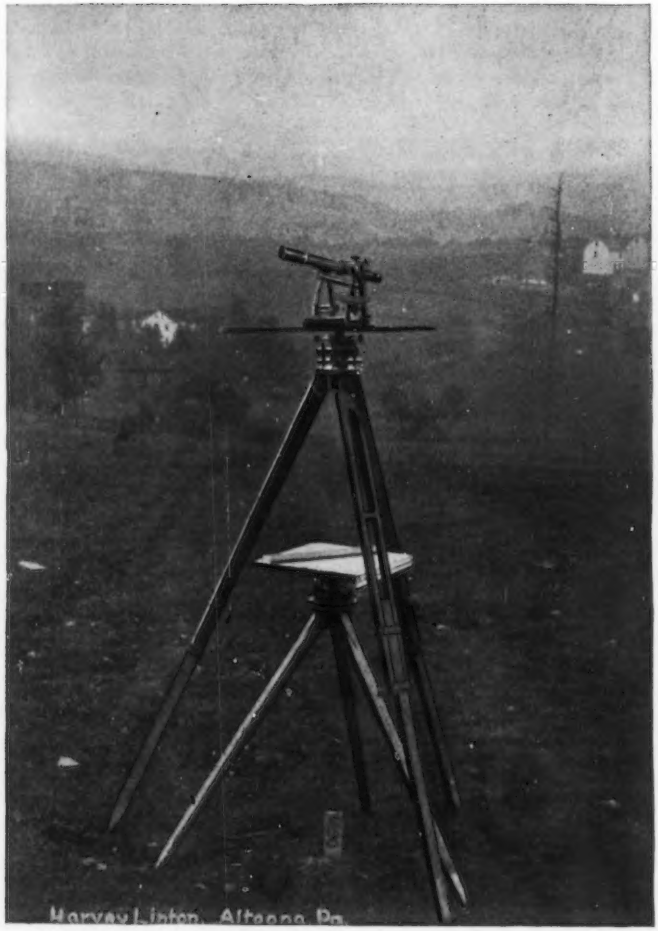
LINTON ON RAILROAD LOCATION.



tions, may be read from both of these stations simultaneously, as a safeguard against any serious errors of observation.

The topography can be plotted in the field in fair weather upon small plane-tables oriented at each station (Plate VIII).

A party of six—two instrument-men, who are also topographers, and four rodmen, each provided with a rod and a light axe—will do much more work in the same time than a larger party, with chain and stakes, and instead of notes they will send into the office sheets of topography, the only field-notes necessary being those relating to the length and bearing of the lines of the survey and the elevations of the stations or turning points.*

Mr. BAILEY WILLIS (by letter).—The location of a railroad is controlled by the topography of the region through which it passes, and topography is related to geology; therefore, as a geologist, I may venture to consider what Mr. Lynch says of topography.

Mr. Lynch rightly says that an engineer should be thoroughly familiar with the drainage of the district, and that he may infer the direction of steeper slopes from the relative nearness of a main stream to a divide. But the broad generalization that the south slope of an east and west valley and the east slope of a north and south valley are steeper than their opposites, is, I think, a conclusion which must admit of as many exceptions as there are instances to support it.

Consider what determines slope. The first condition is difference of elevation and nearness of summit to lowland. But if we eliminate this primary condition and consider slope in two directions from a given summit, we shall recognize that the steeper slope is always across the dip of the rocks, the gentler slope is always with the dip of the beds.

Relief is carved from the rocks by water; soft rocks, yielding, make valleys; hard rocks, resisting, make elevations. If the rocks occur as strata which are alternately hard and soft, the form of relief depends upon the attitude or dip of the beds.

First.—If the strata extend horizontally, the channel carved by any stream is a cañon, having vertical walls in hard rocks, supported by talus slopes in the underlying softer strata. The cañon of the Colorado is the type: examples are common in the Cumberland plateau of Kentucky, and the "table-mountain" or "mesa" is the characteristic hill.

Second.—If the strata are inclined, the work of erosion produces a more or less pronounced cliff-and-talus profile across the dip, and a long gentle slope with the dip. The ridges of the Appalachian belt are the type; examples are common along the foot-hills of the Rockies, and the characteristic form of relief is the long, even-topped ridge.

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*Proceedings of Engineers' Club of Philadelphia, Vol. VIII, No. 2, Topographical Surveying.

Third.—If the strata be vertical, the work of erosion is usually equal on both sides and the ridge is symmetrical. Examples of this occur in the Appalachian belt, and in other zones of upturned rocks.

The subject of topographic form is a very broad one, and I submit these brief comments merely to call attention to the fact that slope is not a function of the point of the compass, as Mr. Lynch seems to imply.

In regard to instruments I note that Mr. Lynch does not mention the plane-table. This instrument is not in favor among railroad engineers, but its development and application in the last five years in the United States Geological Survey may justify the statement that it will be found most useful to them, and particularly in making locations.

CHARLES W. STANIFORD, M. Am. Soc. C. E. (by letter).—During the location and construction of the South Pennsylvania Railroad, from 1881 to 1885, all grades were compensated on curves at the rate of .02 per station per degree of curve, and changes in grade were effected by true parabolic curves, usually about 600 ft. long.

Further than this, after the final location had been adopted and the work let for construction, a degree of exactness in this direction was ordered which I do not think has been attempted on the original construction of many other roads, as follows: On a grade line where the curve compensation makes a lightened gradient for the length of each curve, forming at the beginning and end of same a break in the grade, parabolic curves were introduced at each of these breaks 300 ft. long, running 150 ft. in each direction from the P. C. and P. T. of the curve. These easements eliminate all angularities and transform the entire grade of the road into a series of tangents and parabolic curves.

It would appear that, although the corrections necessary to round these slight breaks in a gradient are usually small, the result from their use is part of the perfection arrived at in the maintenance and improvement of many trunk lines, and that some extra work would therefore be warranted in the calculations for the grades of such roads during the first construction of the roadbed.

As a matter of fact, however, after the elevations had been corrected for these curves, at the beginning of the work, we had no more trouble or labor during construction in using gradients so treated than in similar work on regular grade lines.

P. F. BRENDLINGER, M. Am. Soc. C. E.—The paper before the Society this evening is exceedingly interesting, and should be discussed and entered into with zeal by all the railroad engineers present, for the occupation of "Railroad Location" was, and still is, to a great extent, the idea of the people at large the definition for the business of a civil engineer. The badge we carry is likewise emblematical of the same.

The preparation of the paper shows Mr. Lynch to have covered the subject quite clearly, in the main, and, of course, it would be very

strange if in the matter of details there would be no differences of opinion.

In regard to finding the steepest slopes on the south side of mountain ranges extending east and west, and on the east side when a stream flows north and south, I cannot say that the rule is general, but it seems that the majority of railroads now constructed and in operation do have their maximum grades on the south and east. The Pennsylvania Railroad, the Baltimore and Ohio Railroad, and all roads south of them crossing the Allegheny Mountain Range, to the best of my knowledge, have their steepest grades on the south and east sides. The uncompleted South Pennsylvania Railroad is similarly situated. The Lehigh Valley and the Central Railroad of New Jersey in crossing the Blue Ridge are an exception to this rule. The rule seems to hold good, also, in crossing the Rocky Mountains, with the exception of the Great Northern Railroad.

Chief Engineer Beckler, in his written discussion to-night, does not mention or discuss this part of Mr. Lynch's paper, yet in an article in a late issue of the *Railroad Gazette*, written by Mr. Beckler, he gives the profile of the Great Northern Railroad, which shows that the steepest grades are on the western slopes on the Rocky Mountains.

In my own experience I had never discovered this supposed truism; in fact, it is something new to me, never having seen it in print nor heard of it before.

Reconnaissance.—Mr. Lynch recommends using a gaited horse for making reconnaissances. I think this a rather loose and unsatisfactory method, and, as chief engineer of a road, would hardly pursue it. If a country, through which a reconnaissance is desired, is rough and sparse of good roads, I would have three saddle horses for the party, led during working hours by one man, while the other two men made the reconnaissance with a stadia instrument on foot, or with aneroid and pedometer. At close of the day the horses could be used to find shelter for the night. I have always used the aneroid for reconnaissances and have made some remarkably close observations, frequently having found the difference not more than 4 or 5 ft. from the actual levels in a distance of 10 miles. Mr. Lynch mentions that "settled" weather is necessary for good aneroid work—I presume he means clear weather. I have made just as close observations in cloudy weather as in clear, that is, not partly cloudy and clear, but when the sun was obscured all day.

Camping.—I think Mr. Lynch is rather severe in his censure of stopping at farmhouses while making a survey; he calls it a "one-horse arrangement." Camping out in tents is quite romantic, convenient and sure, but who can estimate or name the number of professional railroad engineers who are not afflicted with rheumatism contracted by camping out? I know, to my sorrow, that I am not an

exception. I always believe in sheltering the members of a surveying party in houses, if possible, and this can always be done if the country is half civilized. There is nothing more conducive to getting good hard work (and lots of it) out of the men than by giving them a good, dry and comfortable shelter at night. Camping out in shelter tents in summer is very pleasant, but when fall and winter come the best thing to do is to get in a house. A good point made by Mr. Lynch is to carry the men to and from the work with teams. I am heartily in accord with him on this point, but it is very dangerous ground on which we walk. The old pioneers in railroad location never had these facilities, and those who are now chief engineers of railroads spurn such a practice, and term it weakness, laziness or dude occupations, and lament the deterioration of the profession. I have always found decided objections by the chief engineer (if he were an old pioneer) to pay for the hire of teams used for such purposes until I had shown conclusively the greater amount of work done by the men, but there are some men who prefer the old-time lumbering stage to the modern express train. My first experience in railroad location was west of the Mississippi River. We camped out in shelter tents from September, 1870, to May, 1871. There were 18 in the party, including two teamsters. The principal assistant engineer had charge of the party. We were routed out of our tents long before daylight, and those who did not respond to the call promptly had the roof drop down on them in quick order. By the time breakfast was disposed of and two sandwiches pocketed for lunch, the start was made for the work, and as a rule it was hardly dawn.

Frequently we had to walk eight miles to our work, then work till dark, never stopping to eat lunch, but snatching a bite, while the transit-man "moved up," until the lunch was finished. I acted as slopeman or topographer and, as the running of the survey lines on preliminary was very rapid, I had to keep up a continuous dog-trot all day, and consequently the lunch was dispatched in rapid transit style. When the work was done for the day, the men were thoroughly exhausted, and it would take hours of weary struggling through swamps, briar and brush patches before camp was reached. The condition of the men, physically and mentally, was such, that if it had not been for a good supper, roaring camp fire, accompanied by banjo and guitar music, the whole party would have mutinied and deserted the next morning. It is wonderful how music, in front of a roaring camp fire, enlivens the men and keeps up the organization.

The beds consisted of straw or hay, obtained from widely scattered farms, laid loosely on the ground, on which were placed two gum blankets followed by as many army blankets as the occupants felt like buying. Two men, occupying one bed, were compelled to buy their own blankets. Frequently when the party got into the new camping

ground, several hours after dark, the teams had just arrived, but no tents were set up. Every man had then to turn in and shovel away the snow, clear the brush and put up the tents; and as no straw or hay was in sight, brush of any kind, or small limbs cut off from trees, were used for the foundation of the blankets. Many a night I climbed up trees with a hatchet to cut down a feather bed. During severe storms, winter or summer, "Tenting on the Old Camp Ground" is much finer when rendered in a cosy drawing-room than out on damp Mother Earth.

Hence, I say, while it may be a "one-horse arrangement," as Mr. Lynch says, to stop at farmhouses, I would prefer to be classed as an advocate of such an arrangement and be comfortable, than to camp out and undergo all kinds of hardships.

Preliminary Survey.—In running the preliminary lines Mr. Lynch says that he uses the vernier exclusively, for ascertaining the direction of his lines.

I consider this exceedingly bad practice, and under no circumstances would I, as chief engineer of a railroad, permit any assistant to run such a line. I know of no reason why the transit-man should not make an error occasionally in reading the amount or direction of angle turned and of recording the same wrong in his note-book. Severe and long experience has taught me that the only practically safe rule or method is to use both vernier and needle, keeping calculated and magnetic courses in the transit-man's note-book, and checking the direction of the angle turned, by compelling the following level and topographical parties to enter in their note-books the turning points, noting whether the line diverges to the right or left. Any one who has tried to develop a large section of country, by means of traverse lines in all directions, connecting them again with the base line, has, no doubt, discovered that there cannot be too many ways of checking the courses and distances.

Taking Topography.—My first experience on surveys was on topography; I was called a slopeman, and comprised the whole of the topographical party. The country was rolling prairie, when away from the river, and varying from flat to steep hill sides along the river. I carried a 50-ft. tape and Locke or hand level. My eyes were practically 5 ft. from the ground, so I took levels to the right and left of the line in heights of 5 ft. I could tell, by keeping my left eye open, whereabout on the ground the cross hairs in the level, as seen by my right eye, apparently pierced the ground. Then, by stepping if the ground was gently sloping, or measuring with tape if steep, I would get the distance in which the ground rose or fell 5 ft. My notes would then be entered thus—

CENTER.

$$\text{etc., etc., } -\frac{5}{60}-\frac{5}{40}\ \Big|\ +\frac{5}{50}+\frac{5}{60}\ \text{etc., etc.}$$

The right-hand side showing plus or rise 5 ft. in 50, etc., the numerator indicating the rise or fall as shown on the left by minus sign, and the denominator the distance. In using the tape line, I always put the ring of the tape in a peg or twig stuck in the ground, then measured back to the point where I had taken observations; and in going down hill, I put the ring in a peg and walked down hill to a point where my level showed I was 5 ft. lower; read the horizontal distance on the tape, then jerked the tape off the peg, and repeated this process till through. This is without question a very crude way of taking slopes, but it is wonderful how accurately a careful and painstaking slopeman can take the topography in this way. My practice is to have the topography party consist of three men. The man in charge keeping notes, sketching streams, etc., and directing the work; while the leveler in the party carries a 5-ft. staff with a V notch cut in the top, on which he rests his Locke level when sighting and holding the box end of a 50-ft. tape, and reads the horizontal distance to the third man, who has a 15-ft. pole divided into feet and halves and the ring end of the 50-ft. tape. I also have the rodman of the level party copy the elevations of each station on a slip of paper, and every 1 000 ft. or so put this slip in a slot in a stake, made with his hatchet, for the use of the topography party, who then, knowing the elevation of each station, can pick out contours exclusively, which simplifies the draughtsman's work very much and renders accuracy more certain. The slope or topography notes must be transferred to a duplicate book every evening. This book always remains in the office or headquarters, and is for the use of the draughtsman to make up his maps the next day; in fact, it is a rule I invariably follow, that all survey notes, transit, level and topography, must be transferred every evening to duplicate books, which are called office books, while the others are termed field books. This is essential to ensure success in any operation on a large scale, for I have known on a number of occasions where field books were lost or completely ruined by falling in streams while crossing. In the coal regions when a book falls in a stream it comes out as black as the ace of spades.

Maps.—Having now run the preliminary line for one day and recorded all the notes in duplicate in the office, the draughtsman takes up the thread and prepares the maps for use in location. I always use for this purpose smooth white paper, termed "Royal," size 19 x 24 ins., and in a comparatively level country use a scale of 400 ft. to 1 in., and in a rough country 200 ft. to 1 in., and always plot the contours in 10-ft. variations. Mr. Lynch recommends a scale of 800 ft. to 1 in.; for my part, I do not see how he can use such a scale and do accurate work unless the country is very flat.

Locating.—When a considerable distance is run by the preliminary party and the maps made up so that I can glean sufficient informa-

tion as to grades and curvature, I block out a paper location in pencil on these sheets or maps and make a profile, and make changes on my location in pencil where my profile requires it. Then, if the railroad is such as Mr. Lynch writes about, 250 miles long, I organize a separate party and call it a "locating party." I provide the man in charge with a wooden box covered with leather or oilcloth, which is carried by the rear flagman, with a strap, while in the field. In this box I have a sufficient number of the aforesaid sheets or papers on which the paper location is projected, a parallel ruler, paper, wood or celluloid curves, two triangles, a straight-edge and thumb tacks. The man in charge then locates on the ground the line blocked out in pencil on the sheets, keeping the line correct by checking on the ground at intersections with (or measuring distance to) the preliminary line shown by the stakes in the ground. If the ground (at any point) is found different from what the contours of the map show, his duty then is to fit the line to the ground at that point, but always with a view to "getting on" to his line again ahead as projected on his sheets; for this purpose the different articles in his box are brought into use. Mr. Lynch says he only projects tangents on the maps of the preliminary surveys, and any good engineer can fit the curve on the ground, and condemns what he calls "a cast-iron location projected on the preliminary maps in the office." I claim that there must be a head to any successful enterprise, whose duty is to block out carefully the work of each department, which must be faithfully carried out by each man as laid out, varied occasionally as the circumstances demand; but if each engineer runs the line to suit himself, there will be a location resulting in nothing but "crazy-quilt" work. There are a number of engineers who spurn to run a location from a projected paper location, claiming they can do better by "the eye." My experience has been that such men, as a rule, are very expensive to the company employing them, both for location and in the subsequent operation of the road. There are, of course, exceptions to this rule as to every other.

I have frequently blocked out work, as mentioned above, for four and six parties at a time, and thus knew just what was being done all the time, and there was a uniformity of action throughout the entire service which could not be obtained in any other way.

The notes of the located line are also transferred to duplicate or office books every evening, and from these notes maps of the same size sheets as previously mentioned, on a scale of 100 ft. to 1 in., are made, with 5-ft. contours.

These maps can be used for blocking out a close revision of the located line, and also for the purpose of laying out the right of way or property to be bought. I always block out the right of way in pencil on these sheets, then take a roll of tracing cloth and split it in two lengthwise. I then have a roll about 18 ins. in width. This I place

on a series of sheets tacked together, trace the located center line and the property or right-of-way lines.

This roll then constitutes my right-of-way map and is my record. Whenever I wish to use a map to attach to a deed, etc., I can always make a separate tracing from the 100-ft. scale map or make a blue print from the 18-in. roll.

Broken-Back Curves.—I agree with Mr. Lynch on broken-back curves. They are of ancient history, and there can hardly be a case where an intermediate curve cannot be placed so as to avoid, not only the unsightly appearance of the line, but the rough riding on trains.

Compensation for Curvature.—Mr. Lynch recommends 0.04 ft. per degree of curve for compensation of grades. I think this a little too high, and would recommend 0.03.

I constructed the Pottsville and Mahanoy Railroad in the Schuylkill coal regions in 1886, and on this line there is a continuous grade of 165 ft. to a mile for nearly four miles. There are numerous sharp and long curves, the maximum being 12°. The compensation for curvature was 0.03 ft. per degree. After the road was completed and in operation, I frequently rode on the locomotives pushing empty coal trains up over this grade. From my own observation, and in conversation with the engineers, I ascertained that the curves required no more work from the engine than the tangents; there was a uniform push all the way up. From this I judge I had about arrived at the proper compensation.

Vertical Curves.—Mr. Lynch seems to have the same distance established from the intersection of two grades for the commencement of the vertical grade, regardless of what the grades may be. I do not think this rule a very good one. I never plot the vertical curves on my regular profile, but take a sheet of cross-section paper—scale 10 ft. to 1 in.—on which I plot the two opposing grades; then I plot an easy curve with a paper curve, and ascertain the elevations at each station intersection. This is a graphical method, and is accompanied by no error in calculation ; is simple and can be varied as much as desired.

Slides.—There is one point in railroad location not covered by Mr. Lynch. That is the knowledge the locating engineer should acquire in going through a country as to the stability of the material along hillsides. If the material overlying rocks at an angle is saturated with water and the foot of the slope is cut into, it is more than likely there will be more material come down from the hillside than was originally in the cut. The only safe way is to have a small embankment, if possible, rather than to cut the slope. My first experience of this kind was in the Monongahela Valley. There was a bank of 60 000 cu. yds. and a cut of 40 000 cu. yds. in close proximity. This necessitated a borrow of 20 000 cu. yds. I made a borrow at the same time I took out the cut. The result was, before the cut was done,

I had to waste about 20 000 cu. yds., as the hill above came sliding down into the cut.

MICHAEL L. LYNCH, M. Am. Soc. C. E. (by letter).—The writer is pleased to learn that the paper under consideration has evoked such general discussion from the many engineers competent by training and experience to throw light on this very interesting and important subject, as also from the scientists who discuss certain laws governing the formation of the earth's surface, which necessarily have a bearing on the general subject. As there seems to be some doubt or misapprehension of the writer's meaning on certain points, possibly through lack of clearness in the original paper, or difficulty in extracting its full meaning from an abstract, he will endeavor to answer the questions developed during the discussion and explain more fully.

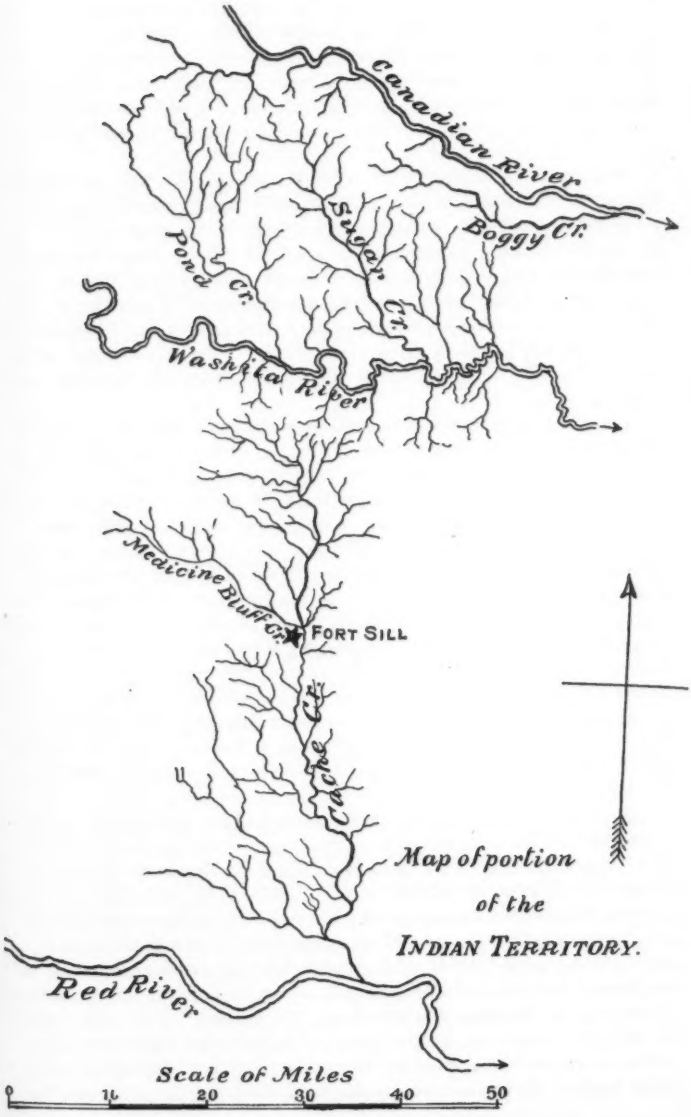
Where Mr. Moore dissents from the writer it probably occurs through some of the above causes, as their ideas are practically the same in all important particulars. The writer's meaning in regard to re-projecting and re-running lines can best be arrived at by considering what precedes it:

"The tangents and curves of the proposed location being first projected on the carefully prepared topographical map of the preliminary lines, before laying off in the field; it often happens, however, that the location so projected can be improved, and the best practice, in the writer's opinion, is to recognize the possible necessity for such a change and be prepared to make it in the field when necessary."

The projection of the location here referred to would, from the nature of the case, necessarily be a calculated one based on the topography as developed by the contours of the preliminary map and the elevations shown on the profile of the preliminary line. By the aid of this projection the location is spotted on the map, and the location of both curves and tangents determined, including intersection angles and the beginning and ends of curves, from which a very close approximate profile of the "paper location" thus projected can be made. This assumes that all the work has been accurately executed, and is the scientific location which it is intended to run in on the ground, and which should be so run in, unless through some inaccuracy of chaining, instrumental work, topography or drafting, some modification that would improve the line became apparent. In this event the paper location should be departed from and the line laid where it would actually fit the ground best, and the engineer should be prepared to re-project and change that part of the line in the field. All engineers of experience on this class of work can no doubt recall many instances where such modification had become necessary, even on paper locations projected by themselves and where it would have been folly to adhere rigidly to any calculated cast-iron location project where it was found in error.

In regard to the methods outlined by Mr. Storey, the writer agrees with him as to the necessity for accurate work in every department, and believes that the main inaccuracies in such work occur in the chaining and topography; this is evidently implied in his description of the method of chaining and of the engineers noting the topography in person on a skeleton plat without contours. The writer is of the opinion, however, that the use of a skilled topographer developing the contours in the usual manner, which are afterwards platted on the preliminary map, is the better plan, as the locating engineer is supposed to have a detailed knowledge of the ground which he utilizes in connection with the contour map in projecting the paper location. Requiring the locating engineer to perform the work of the topographer would necessarily have a tendency to delay the party, by taking his attention from the general direction of the work while performing the duties of a subordinate. The fact that "every half mile or so a check is given, to be taken on the preliminary" is a frank and proper admission of the possibility of error, even in such a carefully conducted survey as Mr. Storey describes, and it seems to the writer that the "machine" he mentions would be liable to "slip an eccentric" in trying to remedy the error otherwise than by intelligent direction on the ground. The writer is not prepared to admit that the methods described by him are expensive. An expensive location is one that is blunderingly executed where a poorly equipped party is put in the field without allowing the locating engineer sufficient time to properly develop the country by a thorough reconnaissance, when it becomes a case of go ahead and back up, until after a certain lapse of time some kind of a line is adopted without any definite knowledge of how it would compare with any other lines in the country. The use of an odometer would certainly give satisfactory results where the country was favorable, and would no doubt be quickly adopted by the engineer. In matters of this kind, transportation of supplies, etc., the engineer is governed by circumstances in general and the character of the country in particular. Often it may become necessary for the greater portion of a reconnaissance to be made on foot.

There seems to be considerable difference of opinion regarding the existence of a general law in connection with the smoother or rougher slopes of a valley. The writer simply noted what came under his own observation, and is fully convinced that such a law exists. By the term valley, he desires to be understood as meaning the slopes on either side approaching a stream, and not alone the contracted space between the foot of slopes. Mr. Kelley, while not fully agreeing with him, cites several instances in corroboration, and in those instances where the conformation is obscure, the streams flow in a southeasterly direction; this latter characteristic was noted in the original paper, its exitsence being more noticeable where the streams lay in the general direction of the meridian or at right angles to it.



Map of portion of the INDIAN TERRITORY.

Mr. Barlow agrees with the writer in regard to the north slope of an east and west valley being generally smoother than the one on the south, and Mr. Maxwell's experience in Washington, Nevada and California leads him to agree with the writer, and while Mr. Brendlinger never had the subject brought to his attention before, he cites several important roads as having their "maximum grades on the south and east."

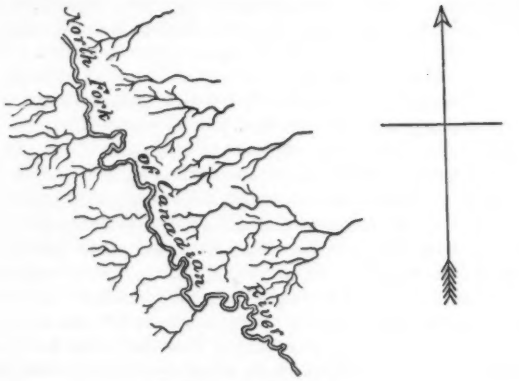
The writer is confident that careful observation will develop the existence of this general law more marked in some cases than in others, always excepting the traditional exception which goes to prove the rule. It is rather a coincidence that all of the three gentlemen who discuss the subject from a scientific standpoint, Messrs. Tarr, Davis and Willis, agree as to the non-existence of such a law, and Mr. Crowell is not quite clear as to the writer's meaning. Probably the sketch (page 127), taken from a sectionized Government map of the Indian Territory, will help to convey the author's meaning more clearly.

Referring to the sketch, the distance between Red River and the Washita is, in round numbers, 65 miles, and of this distance, to the head of Cache Creek, about 60 miles is in the drainage of the Red River, and 5 miles in the drainage of the Washita, resulting in a very steep descent to the latter stream. Continuing north across the Washita along Sugar Creek for about 30 miles to its head we find ourselves within 4 or 5 miles of the Canadian River, to which the descent is consequently very steep. This is a good example of the relative declivity of slopes between streams, and illustrates the writer's meaning where he says that "the engineer will find it more difficult to get a line down into a valley from the south than in leaving the valley going up the north slope." Again, the portion of the north fork of the Canadian River flowing in a southerly direction (see sketch, page 129), taken from the same map, illustrates why it would be "more difficult in getting down the east slope of a valley than in getting up the west slope."

The writer's attention was first drawn to this peculiarity several years since while engaged on a reconnoissance for the Gulf, Colorado and Santa Fé Railway, extending from Northern Texas up through the Indian Territory to the Kansas line, the general direction being across some of the largest streams in the Southwest, where he found this law fully exemplified, with one noticeable exception. He may also mention another very noticeable case of this law relating to streams flowing in the general direction of the meridian, which came under his personal observation in locating the Shreveport extension of the St. Louis Southwestern Railway, between Louisville, Ark., and Shreveport, La.

In this case, the line occupied the country between two streams, both flowing about due south, the Red River on the west, and the

Bayou Bodceau on the east. Upon reconnoissance, it developed that the divide lay close up to the Red River, along its left bank, with such steep, precipitous and broken slopes towards the river that a line was utterly out of the question; whereas, by swinging the line further east towards the drainage of the Bodceau, a tangent 22½ miles in length was obtained with light work. No doubt, certain cases may exist where these conditions do not obtain, or may be reversed; possibly the drainage of the Yellowstone River, in Montana, would be a case in point, but the writer believes them to be rare, and in very broken mountainous country, where serious geological disturbance has taken place, drainages, divides and slopes become mixed up in such inextricable confusion that no law seems to govern, so that, upon whichever side of a stream the engineer may find himself, he is sorry that he is not on the other.



Map of portion
of the
INDIAN TERRITORY.
Scale of Miles
0 10 20 30 40 50

The valleys proper of streams partake, to a certain extent, of the character of the slopes extending back to the divide, it being self-evident that steep bluffs are liable to be found on either side of a stream, depending on how the stream caroms from one side of the valley to the other. Again, some streams have very little valley, partaking more of the nature of a gorge or cañon, in which case the law would not apply as to their valleys. This is a peculiar phase of the subject, and properly belongs to the domain of abstract science rather

than to practical engineering, and is worthy the attention of scientists. The engineer simply notes the fact and takes advantage of it.

The main advantage to an engineer of the knowledge of this law is, that it would direct him on reconnaissance to where he would be liable to find the smoothest ground, and enable him, beforehand, to form an intelligent opinion of a project in general.

A glance at any good map will show many examples of where this condition has been taken advantage of. The Union Pacific keeps along the north bank of the Platte, and where it diverges at Julesburg, one branch keeps up the north bank of Lodge Pole Creek. The Burlington and Missouri Valley road keeps on the north bank of the Republican River, and where it diverges at Culbertson, one branch keeps up the north bank of Whiteman's Creek. The Atchison, Topeka and Santa Fé road keeps on the north bank of the Arkansas River for the greater portion of the distance along that stream. Many other notable examples could be cited, but, of course, when the question of competition and the building of branch lines comes in, a road is liable to occupy either side of a stream.

The discussion by Mr. Ainsworth touches certain points which the writer did not expect to see come up, but which may, nevertheless, be considered pertinent to the subject. It seems, to the writer, that a broad general principle is here involved, and that the way of the engineer is plain. A syndicate or company desires to build a road and employs an engineer; he is engaged under a salary agreed upon, and they are entitled to his best service. They naturally consult him as to the character of line available over a certain country, upon which he advises them; it is not necessary for him to know all the details of their plans, financial or otherwise. They instruct him as to the amount of funds available, which necessarily governs the character of the line, both as to location and construction; he goes ahead and gets the best line available under the conditions, and his work is done. Of course, it may devolve on him at some stage of the proceedings to try to save them from themselves by endeavoring to head them off from some piece of folly and adopt such a line as his better judgment would dictate, but if his suggestions are not adopted, and he receives definite instructions as to their requirements, then he is bound to follow them; provided, always, that no point of honor or ethics is involved, or that the professional work required of him would be of such an inferior character that he would not wish to have his name identified with it.

As to secrecy, of course, the locating engineer should consider that he occupies a position of trust, and has to guard against the professional town boomer and land shark as well as against the avaricious landowner. Right here is where one of the valuable features of a horseback reconnaissance comes in, as it can be performed without disclosing one's intentions to land speculators or competing railroads; as in

ordinary country the general character of a line, including maximum gradient and curvature and approximate estimate of cost, can be determined and an intelligent report furnished, thus enabling one road to take all necessary preliminary steps towards occupying a country without unnecessary warning to a competitor.

Mr. Purdon's discussion contains a series of aphorisms which are sound location doctrine and very much to the point. There is no doubt but that serious mistakes have been made by skirting the foothills of a slope too closely, resulting in a series of alternate light cuts and fills; the resulting light work being liable to washouts from the rapidly descending waters of the slope in heavy rainstorms. Better, as he says, to lay the line on lower ground on moderate embankment and with ample borrow pit or ditch on the up-hill side, to catch the drainage of the slope and convey it safely to the nearest opening. The method of taking topography described by him as used by Mr. Van Sant is new to the writer, and seems to be an ingenious and effective method.

The writer did not mean to convey the idea that general principles should not govern in railroad location as Mr. Beckler and Mr. Brendlinger seem to have inferred. The original paper states that, "in regard to curvature and grades, it is assumed that a certain maximum has been agreed upon which cannot be exceeded," it being understood without saying that no intelligent comparison of two or more lines through a country could be made without considering all the elements that would enter into the completed road as turned over for purposes of operation, including the character of curvature and its amount, character and length of gradients, rise and fall, percentage of curvature and tangent, character and amount of grading, bridging, etc., together with an estimate of cost; in fact, he considers no location profile complete without an estimate on the face of it for each section. He meant to convey the idea, that, as countries and conditions differ, the engineer should be prepared to meet different conditions as they exist, without being governed by inflexible rules. Of course, it should go without saying that no comprehensive system of location could be carried on without intelligent direction and supervision by the chief engineer. In regard to the matter of vertical curves on summits, the writer believes that the method suggested will give curves of sufficient length, even upon steep gradients. Take, for example, two 2% gradients meeting at a summit; under the rule, the ordinate for correction at the apex would be 2 ft., and for the 1st, 2d and 3d stations on either side of the apex the ordinates would be 0.50, 0.13 and 0.03, respectively, the 4th station on either side being the beginning and end of curve, which would result in a curve 800 ft. long, very flat at the ends, it is true, but which, if considered too short, could be modified by the substitution of the method illustrated for two descending

gradients, with sketch of level between. Platting the above to a large scale on cross-section paper will give a good idea of the resulting curve.

The use of the stadia and plane table has been advocated by several gentlemen taking part in the discussion. The writer has a high opinion of the stadia instrument, having used it on United States Government river surveys, and believes it could be profitably used on preliminary railroad surveys, under certain conditions, as distance, azimuth and elevation can be determined by its use. The plane table, of course, is valuable in filling in the details of topography, but, in the writer's opinion, is not needed on railroad surveys. In this connection it should be kept in mind that a detailed accurate topographical map of the entire country is not the object sought, and railroads should not be required to spend money for such a purpose, the main object in view being to get a line on the most suitable ground for the building of a railroad. In accomplishing this result, a great deal must depend upon the individuality of the engineer and his skill in judging country, his mental capacity for absorbing and assimilating a knowledge of what he sees, and of his memory in keeping connected track of the topographic features of a country and utilizing them to the best advantage for his purpose.

In the matter of railroad location, there may be said to exist two schools of extremists, one of which is led by the man with cross hairs in his eye, who would scorn to use a hand level or hand compass, and who pays but the slightest attention to establishing contours on his preliminary map, depending mainly on his eye for results; the other is led by the theoretical crank, who wants to cross-section the whole country with all sorts of instrumental observations, insisting on having everything done according to pet theories regardless of actual consequences. The latter practice has a tendency to narrow and dwarf a man's perceptive faculties, rendering him a species of machine, very slow in operation and dull of perception in grasping the salient features of a country and taking advantage of them, and comparatively helpless when unusual conditions present themselves; while the former will never achieve the best results until he frankly acknowledges to himself that he doesn't know it all, and is willing to call to the aid of his natural judgment the portable instruments and appliances designed for the purpose. A word about treatment of parties in the field, as referred to by Mr. Brendlinger. The writer can sympathize with him, having once been a member of a party which was usually routed out in the latter part of the night, had breakfast eaten and tents down, ready to strike out on foot through the gray dawn for the line, often 4 or 5 miles distant, to be regaled at noon with a lunch consisting of a few hard baked biscuits and some meat carried in a little bundle attached to the buckle strap of each man's pantaloons, the weather being so

extremely hot that no pockets were available owing to lack of wardrobe; then back to camp after the day's work, another long tramp, reaching it after nightfall to a late supper, or, as one of the men wittily put it, "We had two suppers the same night." Such treatment of men is unjustifiable and unworthy of an engineer, and anything but economical or subservient of good work or discipline. The writer is, however, in favor of a party having its own tents and camp outfit. It is much more independent and can do more work, especially in sparsely settled regions, where the accommodations are usually limited and the houses generally small. The writer has more than once been entertained while on reconnaissance where accommodations were so limited that the host, his wife and children and the guest had all to occupy the same sleeping apartment, and he is confident that Mr. Brendlinger and other engineers who may have been similarly entertained will join with him in extolling such as the highest type of hospitality.

Mr. Brendlinger misunderstands the writer in regard to using the vernier alone on preliminary work; the needle should be used as a check by all means, both on preliminary and location.

In regard to taking topography, the various methods described are good, but a good topographer is usually the most difficult man to procure for a party. It seems strange that the engineering schools do not pay more attention to practical field training in this branch through a summer school for field practice during vacation, or at some other suitable time. It is an interesting study, and one to which young men usually take with pleasure.

The question has been asked as to the writer's meaning where he uses the term settled weather in connection with barometric leveling. He means settled weather meteorologically, that is to say, when no atmospheric disturbance is taking place that would interfere with the reading.

The question of bridge location has been fully discussed by Mr. Greiner. Of course, the more the locating engineer knows about bridge construction, and general construction for that matter, the better, but it does not necessarily follow that he should be a bridge expert in order to properly locate the best crossings on a line. The original paper recommends the advisability of locating the best crossings on the important streams, and making the intermediate sections of the line subordinate thereto. The engineer will naturally endeavor to get as square a crossing as he can for every stream, large and small, and for the more important streams take duly into account the nature of approaches, character and stability of banks and bed of stream, and general course of the stream above and below the crossing, and will be careful to show the various high-water marks of previous years on his profile, but, as is well known, the estimate of bridging, like every-

thing else shown for each section on a location profile, is only approximate. The determination of the class and character of structure, general details, etc., is the province of the chief engineer and bridge expert.

The subject of railroad location is a very broad one, and volumes could be written upon it. The discussion and description of methods elicited, while many of the latter are necessarily of old application, will, it is believed, add somewhat of interest to the literature of this very important subject.